US 20020054611A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2002/0054611 A1

SETA (43) Pub. Date: May 9, 2002

(54) TIME SYNCHRONIZATION METHOD IN CDMA SYSTEM

(76) Inventor: MITSURU SETA, KAWASAKI-SHI (JP)

Correspondence Address:
HELGOTT & KARAS
EMPIRE STATE BUILDING
60TH FLOOR
NEW YORK, NY 10118

(*) Notice: This is a publication of a continued prosecution application (CPA) filed under 37 CFR 1.53(d).

(21) Appl. No.: 09/236,962

(22) Filed: Jan. 25, 1999

(30) Foreign Application Priority Data

Jul. 7, 1998 (JP) ..... HEI 10-191472

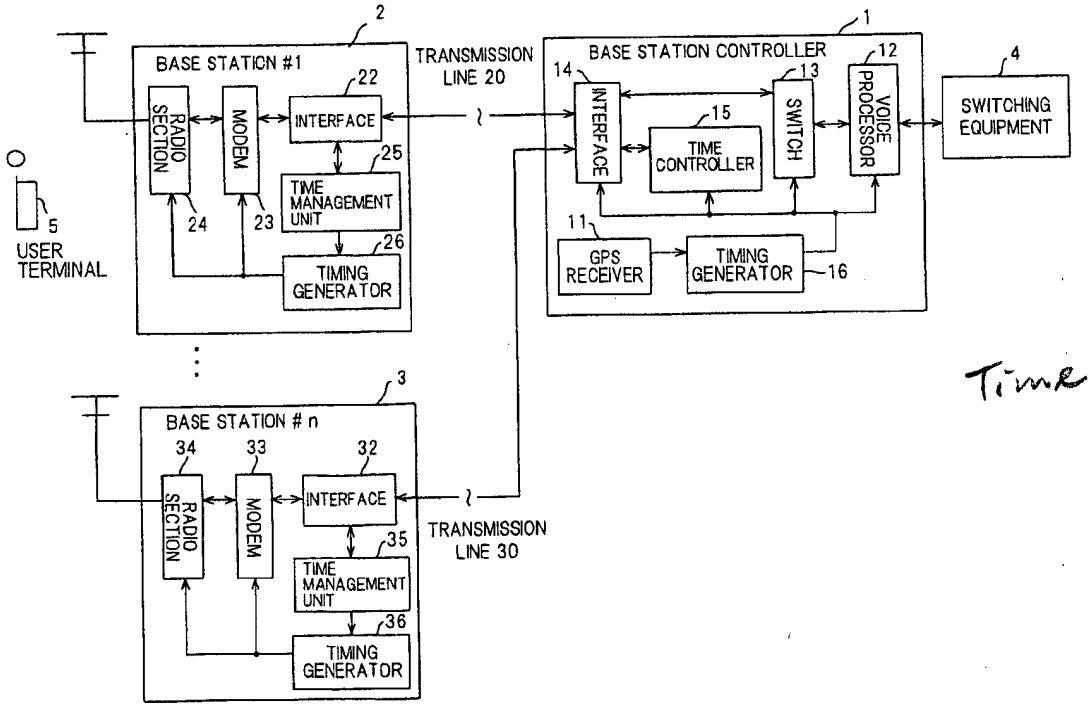
Publication Classification

(51) Int. Cl.[7] H04Q 7/00

(52) U.S. Cl. 370/503; 370/329

(57) ABSTRACT

A time synchronization method in a CDMA system for synchronizing the time of a plurality of base stations and the time of a base station controller that controls each of these base stations includes providing the base station controller with a GPS receiver for receiving a signal from GPS satellites and generating a reference time based upon the received signal, adopting the reference time generated by the GPS receiver as the time of the base station controller, creating time reference information based upon this time and sending the time reference information to each base station. Each base station synchronizes its own time to the that of the base station controller based upon the time reference information it has received.



Time delay

FIG. 1

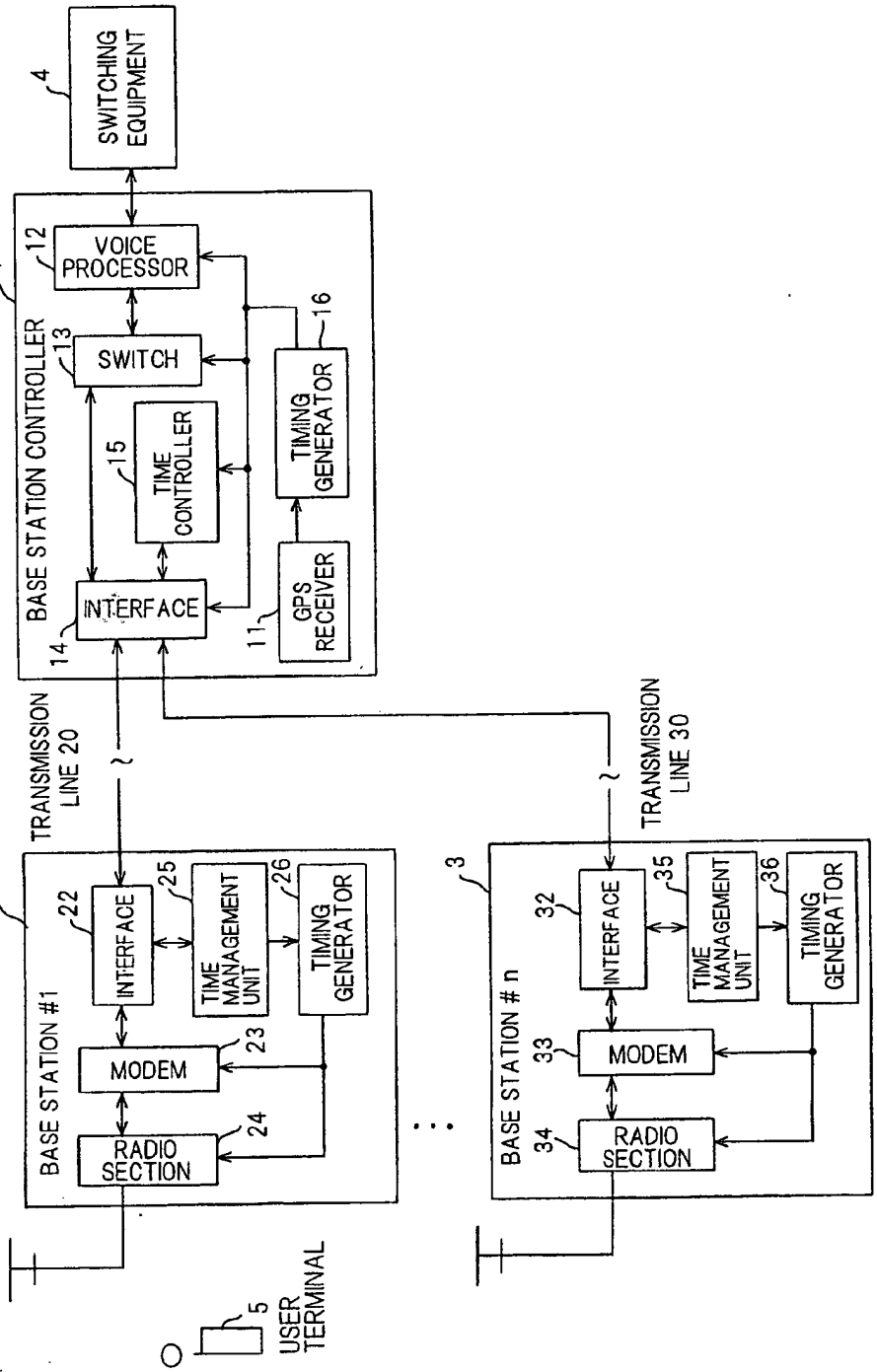

SWITCHING EQUIPMENT
4
BASE STATION CONTROLLER
1
VOICE PROCESSOR
12
SWITCH
13
TIME CONTROLLER
15
INTERFACE
14
TIMING GENERATOR
16
GPS RECEIVER
11
TRANSMISSION LINE 20
TRANSMISSION LINE 30
BASE STATION #1
2
INTERFACE
22
TIME MANAGEMENT UNIT
25
TIMING GENERATOR
26
MODEM
23
RADIO SECTION
24
BASE STATION # n
3
INTERFACE
32
TIME MANAGEMENT UNIT
35
TIMING GENERATOR
36
MODEM
33
RADIO SECTION
34
USER TERMINAL
5

FIG.2

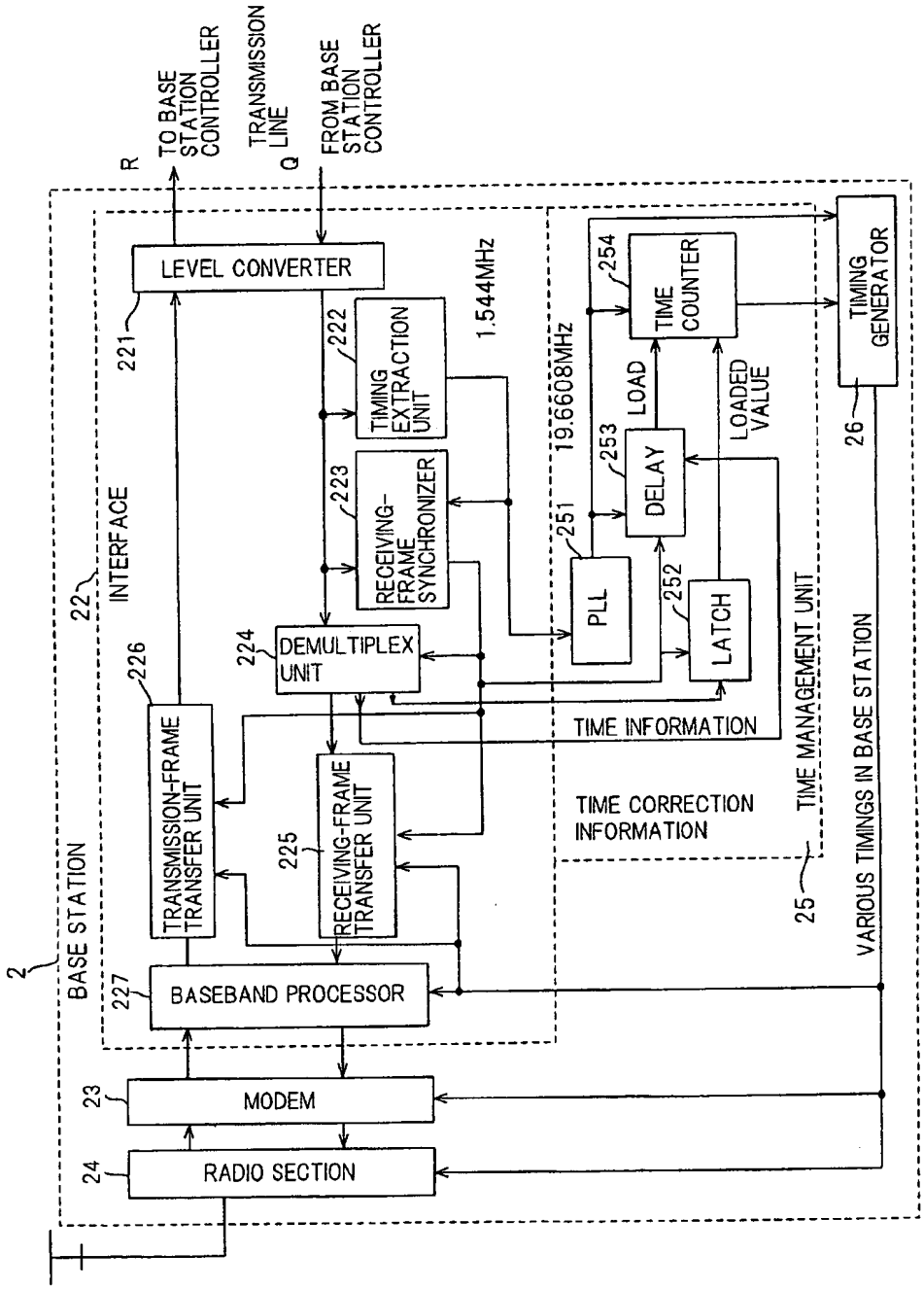

TO BASE STATION CONTROLLER
TRANSMISSION LINE
FROM BASE STATION CONTROLLER
R
Q
LEVEL CONVERTER
221
222
TIMING EXTRACTION UNIT
1.544MHz
223
RECEIVING-FRAME SYNCHRONIZER
224
DEMULTIPLEX UNIT
226
TRANSMISSION-FRAME TRANSFER UNIT
225
RECEIVING-FRAME TRANSFER UNIT
227
BASEBAND PROCESSOR
23
MODEM
24
RADIO SECTION
INTERFACE
22
BASE STATION
2
19.6608MHz
251
PLL
252
LATCH
253
DELAY
LOAD
LOADED VALUE
254
TIME COUNTER
TIMING GENERATOR
26
TIME INFORMATION
TIME CORRECTION INFORMATION
TIME MANAGEMENT UNIT
25
VARIOUS TIMINGS IN BASE STATION

FIG. 3

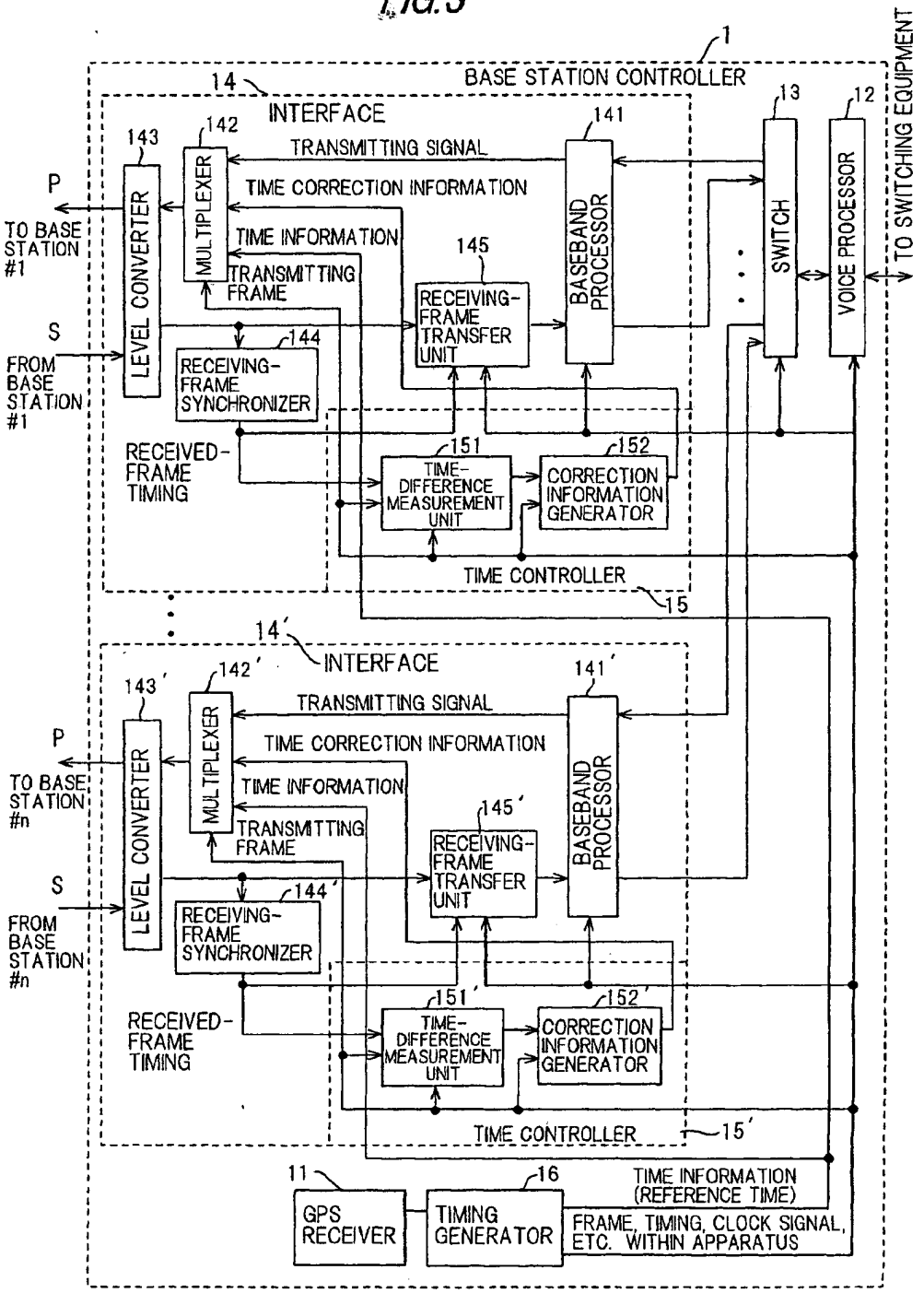

1
BASE STATION CONTROLLER
14
INTERFACE
143
142
141
TRANSMITTING SIGNAL
TIME CORRECTION INFORMATION
TIME INFORMATION
TRANSMITTING FRAME
145
P
TO BASE STATION #1
S
FROM BASE STATION #1
LEVEL CONVERTER
MULTIPLEXER
RECEIVING-FRAME TRANSFER UNIT
BASEBAND PROCESSOR
13
12
SWITCH
VOICE PROCESSOR
TO SWITCHING EQUIPMENT
144
RECEIVING-FRAME SYNCHRONIZER
RECEIVED-FRAME TIMING
151
152
TIME-DIFFERENCE MEASUREMENT UNIT
CORRECTION INFORMATION GENERATOR
TIME CONTROLLER
15
14'
INTERFACE
143'
142'
141'
TRANSMITTING SIGNAL
TIME CORRECTION INFORMATION
TIME INFORMATION
TRANSMITTING FRAME
145'
P
TO BASE STATION #n
S
FROM BASE STATION #n
LEVEL CONVERTER
MULTIPLEXER
RECEIVING-FRAME TRANSFER UNIT
BASEBAND PROCESSOR
144'
RECEIVING-FRAME SYNCHRONIZER
RECEIVED-FRAME TIMING
151'
152'
TIME-DIFFERENCE MEASUREMENT UNIT
CORRECTION INFORMATION GENERATOR
TIME CONTROLLER
15'
11
16
GPS RECEIVER
TIMING GENERATOR
TIME INFORMATION (REFERENCE TIME)
FRAME, TIMING, CLOCK SIGNAL, ETC. WITHIN APPARATUS

FIG.4

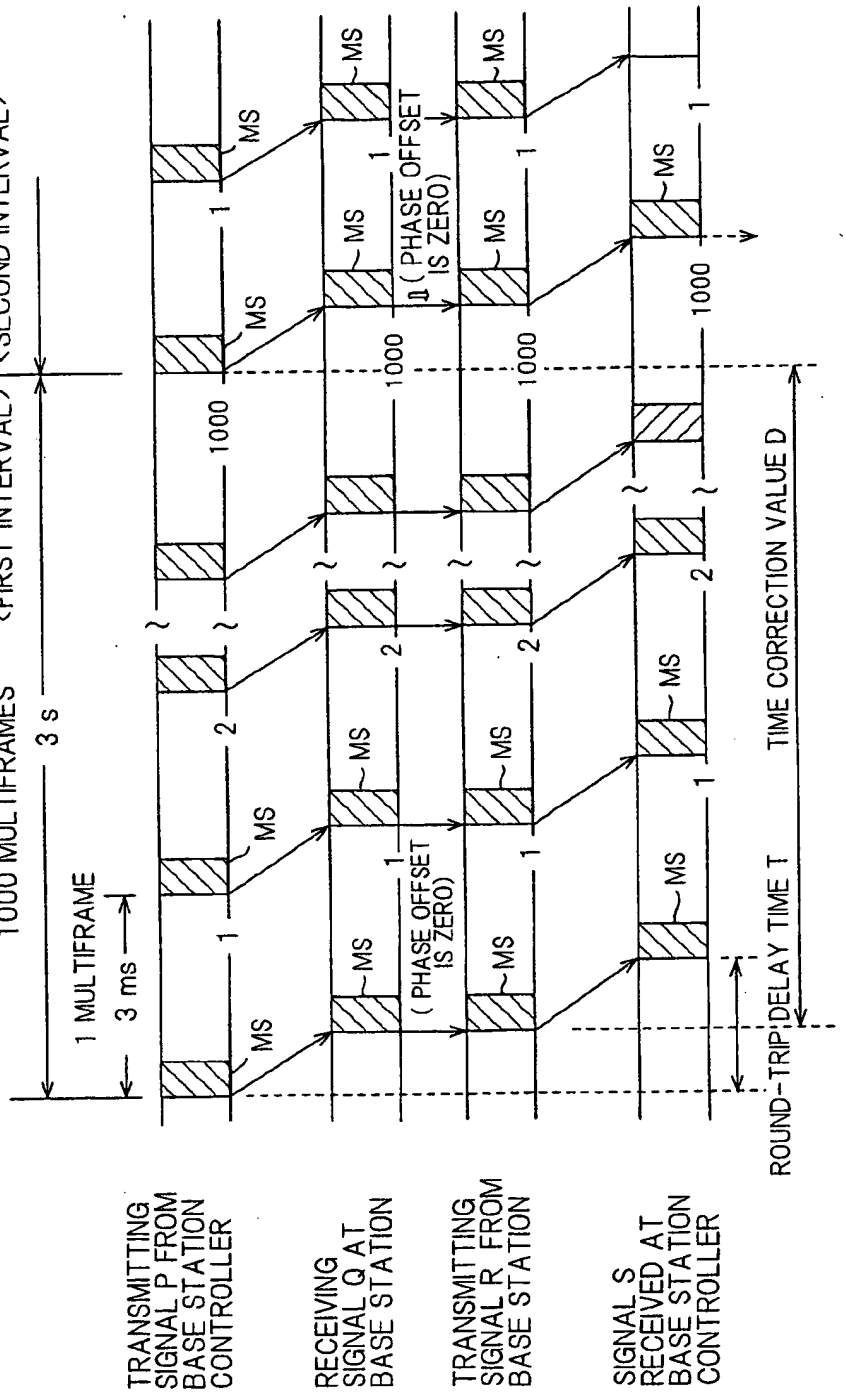
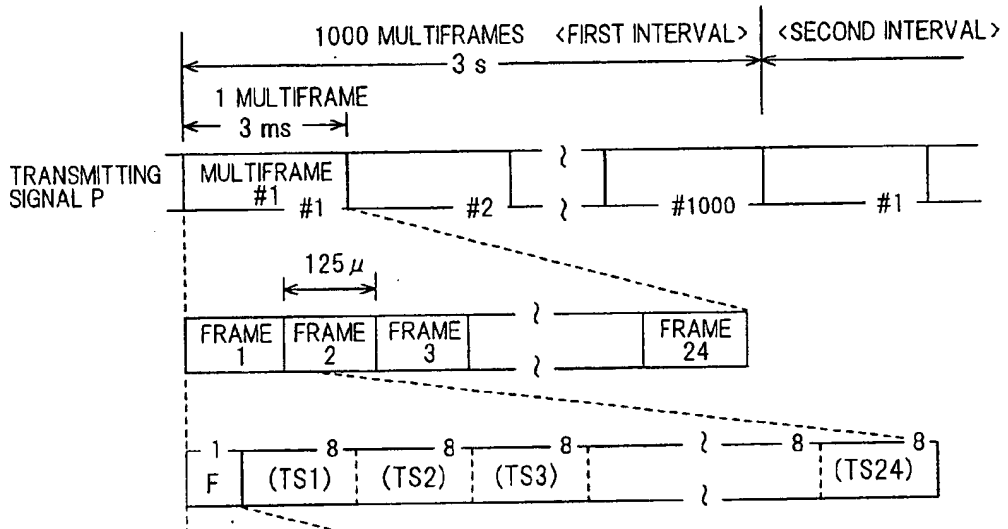

1000 MULTIFRAMES
3 s
<FIRST INTERVAL>
<SECOND INTERVAL>
1 MULTIFRAME
3 ms
MS
1000
(PHASE OFFSET IS ZERO)
TRANSMITTING SIGNAL P FROM BASE STATION CONTROLLER
RECEIVING SIGNAL Q AT BASE STATION
TRANSMITTING SIGNAL R FROM BASE STATION
SIGNAL S RECEIVED AT BASE STATION CONTROLLER
ROUND-TRIP DELAY TIME T
TIME CORRECTION VALUE D

FIG.5



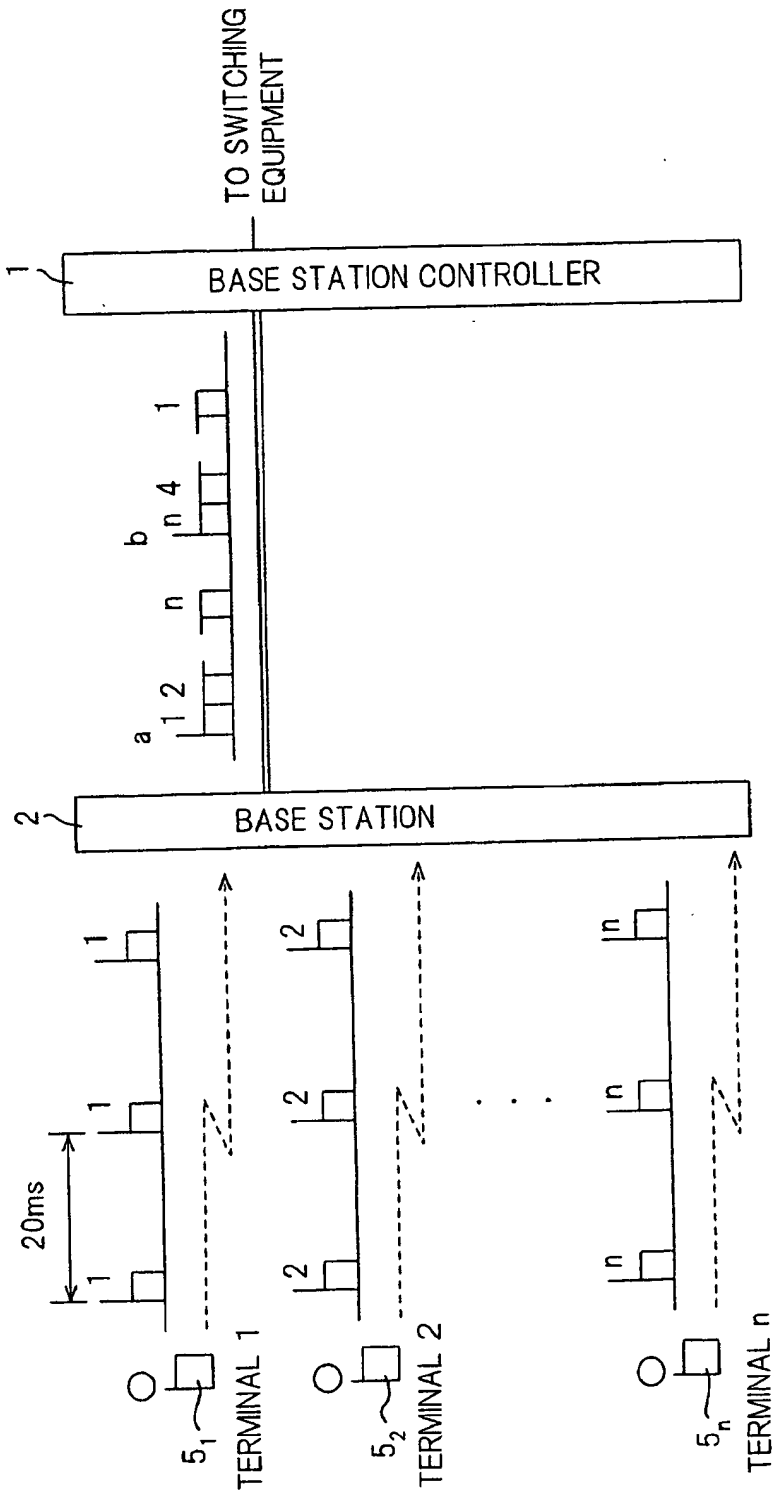
FRAME NO.	F BIT		
	FAS	DL	CRC
1	—	m_1	—
2	—	—	e_1
3	—	m_2	—
4	0	—	—
5	—	m_3	—
6	—	—	e_2
7	—	m_4	—
8	0	—	—
9	—	m_5	—
10	—	—	e_3
11	—	m_6	—
12	1	—	—
13	—	m_7	—
14	—	—	e_4
15	—	m_8	—
16	0	—	—
17	—	m_9	—
18	—	—	e_5
19	—	m_{10}	—
20	1	—	—
21	—	m_{11}	—
22	—	—	e_6
23	—	m_{12}	—
24	1	—	—

FIG. 6

MULTIFRAME NO.	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}
#1	1	1	YEAR (THOUSANDS PLACE)				YEAR (HUNDREDS PLACE)				—	—
#2	0	0	YEAR (TENS PLACE)				YEAR (UNITS PLACE)				—	—
#3	0	0	MONTH (TENS PLACE)				MONTH (UNITS PLACE)				—	—
#4	0	0	DAY (TENS PLACE)				DAY (UNITS PLACE)				—	—
#5	0	0	HOUR (TENS PLACE)				HOUR (UNITS PLACE)				—	—
#6	0	0	MINUTE (TENS PLACE)				MINUTE (UNITS PLACE)				—	—
#7	0	0	SECOND (TENS PLACE)				SECOND (UNITS PLACE)				—	—
#8	0	0	b_{31}	b_{30}	b_{29}	b_{28}	b_{27}	b_{26}	b_{25}	b_{24}	—	—
#9	0	0	b_{23}	b_{22}	b_{21}	b_{20}	b_{19}	b_{18}	b_{17}	b_{16}	—	—
#10	0	0	b_{15}	b_{14}	b_{13}	b_{12}	b_{11}	b_{10}	b_9	b_8	—	—
#11	0	0	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0	—	—
#12	0	0	—	—	—	—	—	—	—	—	—	—
~	~	~	~	~	~	~	~	~	~	~	~	~
#1000	0	0	—	—	—	—	—	—	—	—	—	—

"—" : UNDEFINED (E.G., 0)

FIG.7 PRIOR ART



TIME SYNCHRONIZATION METHOD IN CDMA SYSTEM

BACKGROUND OF THE INVENTION

[0001] This invention relates to a method of synchronizing time in a CDMA system and, more particularly, to a time synchronization method for synchronizing the time of a plurality of base stations and the time of a base station controller that controls these base stations in a CDMA system.

[0002] In an IS-95-based N-CDMA (Narrow-band Code Division Multiple Access) system, it is required that signals transmitted from all base stations be synchronized in time (to within $\pm 3\mu s$ of absolute time) for the following two reasons:

[0003] (1) In an N-CDMA system, a base station is identified by the phase offset of a pilot PN sequence, which is a code string, where PN stands for pseudo-random noise. If base stations are not synchronized in time, the phase offset cannot be stipulated and a terminal such as a cellular telephone will not be able to identify the base station.

[0004] More specifically, signals transmitted from each base station to a mobile terminal include a pilot signal and a synchronizing signal, and each base station transmits these signals upon spreading and modulating the signals by a pilot PN sequence. Though the pilot PN sequence code string used is itself the same for each base station, each base station is provided with a different phase offset (a 64-chip unit) so that the mobile terminal can identify the particular base station. (A maximum of 512 base stations can be identified.) The reference for the phase offset is CDMA system time. In regard to a pilot PN sequence for which the phase offset is 0 (zero), the standard is that 15 consecutive "0"s followed by a "1" be output at time 00:00:00 on Jan. 6, 1980 (the moment at which the changeover from 0 to 1 is made is time 00:00:00). Unless the base stations are synchronized in time, therefore, it is not possible to stipulate the phase offset of the pilot PN sequence and, as a result, it will not be possible for a mobile terminal to identify to which base station it is wirelessly connected.

[0005] (2) In order to avoid transmission line congestion and a fluctuation in transmission delay that accompanies such congestion in an N-CDMA system, phase offsets are imposed on the traffic channels (a traffic channel is a channel for voice signals between a mobile terminal and a base station) in steps of 1.25 ms on a per-call basis. If base stations are not synchronized to one another in terms of time, therefore, it will no longer be possible to implement soft handoff between base stations, soft handoff being a characterizing feature of an N-CDMA system. (Soft handoff is the ability of a mobile station to move from one base station to another without an interruption in service.)

[0006] More specifically, an example of a signal sent and received between each base station and a mobile terminal is a voice signal transmitted via a traffic channel. In order to avoid the effects of congestion, delay and a fluctuation in delay time in the transmission lines between base stations and a base station controller and between the base station controller and switching equipment or the like, phase offsets are allocated to the voice signals in steps of 1.25 ms per call on each traffic channel. Since a 20-ms frame is partitioned into units of 1.25 ms, in such case there will be 16 offsets.

[0007] **FIG. 7** is a diagram useful in describing the necessity of a phase offset. Shown in **FIG. 1** are a base station controller **1**, a base station **2** and mobile terminals $5_1, 5_2, \ldots, 5_n$ currently communicating with the base station **2**. Though data transmission from each terminal is illustrated in the form of bursts in order to make it easier to visualize operation, in actuality the data is transmitted continuously or discretely along the time axis. When voice signals from the terminals $5_1, 5_2, \ldots, 5_n$ arrive at the base station **2** at the same timing, as shown in **FIG. 7**, the signals are queued because there is only one transmission line between the base station **2** and the base station controller **1**. As a consequence, a certain signal will be sent from the base station **2** to the base station controller **1** late in terms of the numerical order. For example, in terms of the numerical order, a voice signal n is sent late at a timing a in **FIG. 7**, and a voice signal **1** is sent late at a timing b. If the queuing time and the numerical order are always constant, no problems arise. However, since the terminals move, a slight disparity develops in the order in which the voice signals arrive at the base station **2**. When the order of signal arrival differs, the order in which signals are sent from the base station to the base station controller **1** also changes and, as a result, a large variation in transmission delay time is produced. For this reason the 1.25-ms offset is set for each call and only two to three terminals are allocated to one offset to prevent a large fluctuation in transmission time.

[0008] Hitless handoff (soft handoff) between base stations under the control of the same base station controller is possible on the condition that the radio frequency before and after handoff is the same and, moreover, that the phase offset allocated to the traffic channels is the same. If the radio frequency is different, an interruption in service will be unavoidable owing to the frequency changeover. If the phase offset is different, this will result in a long standby time at a voice decoder or the like and eventually lead to an interruption in service. It should be noted that one item of voice data should be receivable in 20 ms and that any fluctuation is less than 1.25 ms at most.

[0009] Unless the base stations are synchronized in time, therefore, specifying the same offset before and after handoff will be meaningless and hitless soft handoff will be impossible to accomplish.

[0010] In view of reasons (1) and (2) set forth above, a first CDMA system according to the prior art is such that a highly accurate GPS receiver (having a time error on the order of $\pm 0.1\ \mu s$) is deployed at all base stations and the circuitry in each base station is actuated based upon time information and a clock signal received from GPS satellites.

[0011] With a second CDMA system according to the prior art, namely the system disclosed in the specification of Japanese Patent Application Laid-Open (KOKAI) No. 8-265838, a GPS clock output by a highly accurate GPS receiver deployed at a base station controller is adopted as a master clock and base stations are kept in frequency and time synchronization taking into account the transmission delay time between the base station controller and each base station. According to this second CDMA system, the transmission delay time is measured immediately prior to the sending and receiving of voice signals.

[0012] The first CDMA system according to the prior art is disadvantageous owing to the high cost of the base

stations and system overall. The high-precision GPS receiver is costly (several hundred thousand yen) and a redundant configuration is necessary in order to reduce base station downtime due to failure. Furthermore, since an inexpensive GPS receiver has a time error on the order of 2 to 3 μs, such a receiver cannot meet the system specifications.

[0013] The second CDMA system according to the prior art is capable of maintaining the time and phase synchronization between the base station controller and base stations but a problem that arises is that the base stations themselves cannot achieve time synchronization to absolute time (or to a specific time standard). Further, the second CDMA system is such that transmission delay time is not measured periodically but only just prior to sending/receiving of a voice signal (voice communication). This means that the system cannot deal with a situation in which the transmitting apparatus re-synchronizes for some reason or in which the apparatus recovers after the occurrence of a failure.

SUMMARY OF THE INVENTION

[0014] Accordingly, an object of the present invention is to provide a time synchronization method through which the time of all base stations can be synchronized to absolute time highly accurately without providing each base station with a GPS receiver, i.e., by a low-cost arrangement.

[0015] Another object of the present invention is to provide a time synchronization method through which communication can be performed correctly by synchronizing transmitted signals from all base stations in a highly accurate manner.

[0016] A further object of the present invention is to provide a time synchronization method through which the time of all base stations can be synchronized to absolute time, resulting in that a signal to be transmitted can be transmitted upon synchronizing it to a transmitted signal from another base station even if a transmitting apparatus performs re-synchronization for some reason or recovers after the occurrence of a failure.

[0017] In accordance with the present invention, the foregoing objects are attained by providing a time synchronization method for synchronizing the time of a plurality of base stations in a CDMA system and the time of a base station controller that controls each of these base stations, comprising the steps of (1) providing the base station controller with a GPS receiver for receiving a signal from GPS satellites and generating a reference time based upon the received signal; (2) adopting the reference time generated by the GPS receiver as the time of the base station controller, generating time reference information based upon the said time and sending the time reference information to each base station; and (3) synchronizing the time of each base station to the time of the base station controller based upon the time reference information received by each base station. In other words, only the base station controller is provided with a GPS receiver, time reference information is sent from the base station controller to each base station and the time of each base station is synchronized to the time of the base station controller. This makes it possible to synchronize the time of all base stations to absolute time highly accurately through an inexpensive arrangement. In addition, since absolute time can be made the same at all base stations, signals to be transmitted from each of the base stations can be transmitted upon being synchronized highly accurately and it is possible to perform communication that does not cause transmission line congestion and a fluctuation in transmission delay that accompanies it.

[0018] Further, the base station controller periodically transmits, to each base station as the time reference information, data for specifying the reference time and time correction data for each base station, and the base station uses the reference time specifying data and the time correction data to correct its own time to that of the base station controller. If this arrangement is adopted, the time in the base station can be synchronized momentarily even if the base station re-synchronizes for some reason or recovers after the occurrence of a failure, and the signal to be transmitted can be transmitted upon achieving synchronization with transmitted signals from other base stations.

[0019] In this case the base station controller measures the transmission delay time from the base station controller to a base station, based upon the frame timing of a signal transmitted to the base station and the frame timing of the signal received from each base station, creates time correction data proper to each base station, using this transmission delay time and transmits the time correction data to each base station. Each base station then corrects its own time to that of the base station controller using the reference time specifying data and time correction data.

[0020] Further, the base station controller measures the transmission delay time from the base station controller to a base station based upon the frame timing of a signal transmitted to the base station and the frame timing of the signal received from the base station, adds this transmission delay time to the reference time to create the time reference information and then transmits the time reference information to each base station. Each base station then synchronizes its own time to that of the base station controller based upon the time reference information that has been received.

[0021] Further, the base station controller measures, every n frames, the transmission delay time from the base station controller to a base station based upon the frame timing of a signal transmitted to the base station and the frame timing of the signal received from the base station, adopts a reference time that follows n frames as the reference time specifying data, adopts time obtained by subtracting the transmission delay time from the period of n frames as the time correction data, and transmits this reference time specifying data and time correction data to each base station. Upon elapse of time indicated by the time correction data, each base station makes its own time agree with the reference time indicated by the reference time specifying data.

[0022] Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] **FIG. 1** is a block diagram showing the overall configuration of the present invention;

[0024] **FIG. 2** is a block diagram of a base station;

[0025] **FIG. 3** is a block diagram of a base station controller;

[0026] FIG. 4 is a diagram useful in describing measurement of transmission delay time and a method of giving notification of time information and time correction information;

[0027] FIG. 5 is a diagram useful in describing signal format;

[0028] FIG. 6 is a diagram useful in describing time information and time correction information based upon DL bits; and

[0029] FIG. 7 is a descriptive view illustrating the necessity of phase offset.

DESCRIPTION OF THE PREFERRED EMBODIMENT

(a) Overall Configuration of CDMA System

[0030] FIG. 1 is a block diagram showing the overall configuration of a CDMA system that includes a base station controller and a plurality of base stations (base station devices). Shown in FIG. 1 are the base station controller 1, which controls a plurality of base stations deployed in various areas; base stations 2, 3 deployed in respective areas for controlling/communicating with each of a plurality of user terminals (cellular telephones or the like); switching equipment 4 connecting the base station controller 1 and a communications network for switching voice signals and the like to a desired path; and a user terminal 5. The base station controller 1 and base station 3 are connected by a single transmission line 20, and the base station controller 1 and base station 3 also are connected by a single transmission line 30.

[0031] The base station controller 1 includes a GPS receiver 11 for generating a reference time internally of the unit and a clock signal based upon a GPS signal received from GPS satellites; a voice processor 12 for performing a conversion between voice coding (QCELP) over radio sections (namely between the user terminal and base station) and voice coding (PCM) in the switching network; a switch (SW) 13 for sending signals from the base stations 2, 3 to a prescribed port on the switching equipment 4 and for sending a signal from the switching equipment 4 to the prescribed base station; a base station interface 14 which executes interfacing processing for performing a signal format conversion between the base stations 2, 3 and switch 13; a time controller 15 for transmitting time information (reference time) to each base station, measuring transmission delay time of each base station, creating time correction information based upon the results of measurement and notifying each base station of the time is correction information; and a timing generator 16 which, on the basis of the reference time and clock signal that enter from the GPS receiver 11, generates various timing signals necessary within the base station controller 1 and inputs these timing signals to the components 12 to 15.

[0032] The base station 2 includes an interface 22 for performing a signal conversion between the base station controller 1 and a modem 23; the modem 23, which is for modulating/demodulating (spreading/despreading; quadrature modulating/quadrature detecting; etc.) a call control signal and voice signal in accordance with the CDMA standard; a radio section 24 for converting a baseband signal output by the modem 23 to a high-frequency signal, amplifying the high-frequency signal and transmitting it from an antenna, and for subjecting a high-frequency signal received from the antenna to an operation that is the reverse of that performed at the time of transmission and inputting the resulting signal to the modem 23; a time management unit 25 for generating/managing time and reference timing within the base station 2 using reference time information and time correction information sent from the base station controller 1; and a timing generator 26 which, on the basis of reference timing input from the time management unit 25, generates various timing signals necessary within the base station 2.

[0033] The structure of the base station 3 is the same as that of the base station 2 and has components (an interface 32, a modem 33, a radio section 34, a time management unit 35 and a timing generator 36), whose operation is identical with those of the corresponding components 22 to 26, respectively, of the base station 2.

[0034] The interface 14 in base station controller 1 synchronizes signals, which are to be sent to the base stations 2, 3, to a timing signal that enters from the timing generator 16 and then transmits the signals over the transmission lines 20, 30. The timing signal is synchronized to the reference time output by the GPS receiver 11. The signals sent to the base stations 2, 3 include (1) the usual control signal and voice signal and, in addition (2) reference time information and time correction information needed to synchronize the base stations to the reference time. The time controller 15 detects the transmission delay time between the base station controller 1 and the base stations 2, 3 periodically and creates the time correction information using this transmission delay time.

[0035] The time management units 25, 35 of the base stations 2, 3 each generate time and reference timing within the respective base stations 2, 3 based upon the reference time information and time correction information extracted from the signals sent from the base station controller 1. The timing generators 26, 36 generate various required timing signals and distribute these signals to the components 22 to 24, 32 to 34 within the respective base stations. The interfaces 22, 32 adjust, to prescribed values, the phases between signals received from the base station controller 1 and signals transmitted to the base station controller 1.

(b) Overview of Operation

[0036] The base station controller 1, which operates in synchronization with the time reference signal (reference time and clock signal) output by the GPS receiver 11, sends signals to the base stations 2, 3 in synchronization with the time reference signal and notifies the base stations 2, 3 of the reference time information and time correction information periodically.

[0037] Upon receiving the above-mentioned information from the base station controller 1, the base stations 2, 3 transmit signals to the base station controller 1 at prescribed time phases with respect to the received signals. As a result, the base station controller 1 measures the transmission delay time between the base station controller 1 and the base stations 2, 3, based on the timing at which the signals are transmitted to the base stations and the timing at which the corresponding signals are received from the base stations.

[0038] Further, the base stations **2, 3** extract the reference time information and time correction information from the signals received from the base station controller **1** and, on the basis of the extracted information, make their own internal time coincide with the reference time internally of the base station controller **1**.

[0039] Thus, since each of the base stations **2, 3** is capable of reproducing the same reference time as that of the base station controller **1**, it is possible to operate all base stations **2, 3** in an accurately time-synchronized state. Further, the base station controller **1** measures the transmission delay time between itself and the base stations **2, 3** periodically. Even if a failure should happen to occur in the transmission lines between the base station controller **1** and base stations **2, 3**, the reference time can be reproduced on the side of the base stations **2, 3** immediately after recovery, thus making communication possible.

(c) Details of Base Station Structure

[0040] **FIG. 2** is a detailed block diagram of a base station, in which components identical with those shown in **FIG. 1** are designated by same reference characters. Though the structure of the base station **2** is shown in **FIG. 2**, it should be noted that the base station **3** has exactly the same structure.

[0041] As shown in **FIG. 2**, the interface **22** has a level converter **221** for converting the electrical levels of transmission-line signals R, Q and of signals within the base station **2**. A timing extraction unit **222** extracts a clock component (e.g., 1544 kHz) from the transmission-line signal Q sent from the base station controller **1**. A receiving-frame synchronizer **223** acquires the frame timing of the transmission-line signal Q sent from the base station controller **1**. A demultiplex unit **224** extracts the reference time information and time correction information sent from the base station controller **1**, inputs these items of information to the time management unit **25**, and inputs the voice signals and the like to a receiving-frame transfer unit **225**. The receiving-frame transfer unit **225** transfers from the received frame timing on the transmission line Q to the frame timing within the base station **2**. The frame timing within the base station **2** is synchronized to the time generated by the time management unit **25** and is delivered as the output of the timing generator **26**. A transmission-frame transfer unit **226** transfers from the frame timing within the base station **2** to the transmission frame timing on the transmission line R. This unit assembles a transmission frame based upon a prescribed phase difference (e.g., a phase difference of zero) with a received frame from the base station controller and transmits the frame to the base station controller **1**. A baseband processor **227** performs an operation such as signal termination, data format conversion and so on.

[0042] The time management unit **25** includes a PLL **251** for obtaining a higher frequency (e.g., 19.6608 MHz) phase-synchronized to the clock component (1544 kHz) extracted by the timing extraction unit **222**. This is same frequency as that used to obtain the time correction information, etc., in the base station controller **1**. A latch circuit **252** temporarily latches the time information (reference time) extracted by the demultiplex unit **224**. The time information (reference time) is eventually loaded into a time counter **254** (described later). A delay circuit **253** delays the received-frame timing, which is acquired by the receiving-frame synchronizer **223**, by a certain period of time indicated by the time correction information extracted by the demultiplex unit **224**. The delay circuit **253** loads the time information (reference time) in the time counter **254** at the delayed timing. The time counter **254** performs timekeeping within the base station **2**. Adopting the above-mentioned loaded value as the initial value, the time counter **254** then counts the 19.6608-MHz clock output by the PLL **251**. As a result, time synchronized to the reference time of the base station controller **1** can be kept track of by the base station **2** using the time counter **254**.

[0043] Thus, the base stations **2, 3** operate at a timing synchronized to the clock signal, which is extracted from the transmission-line signal Q that enters from the transmission lines **20, 30**, and can produce a timing synchronized to the reference time of the base station controller **1**. This makes possible operation in which all base stations **2, 3** are synchronized. Further, each of the base stations **2, 3** is capable of sending a transmission frame to the base station controller **1** at a prescribed, fixed phase difference with respect to the phase of frames received from the base station controller **1**. As a consequence, it is possible for the base station controller **1** to measure transmission delay time, as will be described below.

(d) Structural Details of Base Station Controller

[0044] **FIG. 3** is a detailed block diagram of the base station controller **1**, in which components identical with those shown in **FIG. 1** are designated by same reference characters. The base station controller **1** is provided with identically constructed interfaces **14, 14'** corresponding to the base stations **2, 3**, respectively.

[0045] The interfaces **14, 14'** respectively have baseband processors **141, 141'** for terminating signals; multiplexers **142, 142'** for multiplexing the time information (reference time) output by the timing generator **16** and the time correction information output by time controllers **15, 15'** onto the original signals to be transmitted; level converters **143, 143'** for converting the electrical levels of transmission-line signals P, S and of signals within the base station controller **1**; receiving-frame synchronizers **144, 144'** for acquiring the frame period included in the transmission-line signals S sent from the base stations **2, 3**; and receiving-frame transfer units **145, 145'** for transferring from the frame timing on the transmission line S to the frame timing within the base station controller **1**, i.e., to the timing synchronized to the reference time generated by the GPS receiver **11**.

[0046] The time controllers **15, 15'** have time-difference measurement units **151, 151'**, respectively, for measuring the time differences between the frame timing (the frame timing within the apparatus) at which signals are transmitted to the base stations **2, 3** and the frame timings at which signals are received from these base stations. The time differences are measured using a comparatively high-frequency clock of, say, 19.6608 MHz. In order for the time correction information to be generated based upon the time difference, a clock having the same frequency of 19.6608 MHz synchronized to this clock is used in the base stations **2, 3** as well. Though a method of measuring time difference using frame timing as the reference is described here, it is also possible to measure time difference using an existing marker whose period is longer than that of a frame or a multiframe (e.g., 3 ms) in case that the transmission line and its delay is long.

[0047] The time controllers **15, 15'** further include correction information generators **152, 152'**, respectively, for calculating one-way transmission delay time from the time differences measured by the time-difference measurement units **151, 151'**, respectively, namely from the transmission delay time (round-trip delay+time offset on the base station side) from the base station controller **1** to the base stations **2, 3**, and for generating correction information based upon the one-way transmission delay time. (This will be described later in detail.)

[0048] By virtue of this arrangement, the base station controller **1** can send signals to the base stations **2, 3** in sync with the reference time extracted by the GPS receiver **11** in the base station controller **1**, measure the delay in transmission from the base station controller **1** to the base stations **2, 3** and send time information and time correction information to the base stations **2, 3**.

(e) Measurement of Transmission Delay and Method of Notifying of time Information and time Correction Information

[0049] **FIG. 4** is a diagram useful in describing measurement of transmission delay between the base station controller **1** and base stations **2, 3** and a method of giving notification of the time information and time correction information.

[0050] In **FIG. 4**, the character P represents a transmitting signal from the base station controller **1** to the base stations **2, 3**; Q a receiving signal at the base stations **2, 3**; R a transmitting signal from the base stations **2, 3** to the base station controller **1**; and S a receiving signal at the base station controller **1**. The frame length of these signals is 125 μs, a 3-ms multiframe is formed by **24** frames, and a multiframe synchronizing code MS is inserted into the beginning of each multiframe. An interval of 3 s is formed by 1000 multiframes, transmission delay time is measured every 3 seconds and the time of the base stations **2, 3** is synchronized to the reference time of the base station controller **1**.

[0051] The multiframe synchronizing code MS of the signal P transmitted from the base station controller **1** to the base stations **2, 3** is utilized to detect transmission delay time. The base stations **2, 3** operate in such a manner that the phase difference between the multiframe of the signal Q received from the base station controller **1** and the multiframe of the signal R transmitted to the base station controller **1** is kept at a predetermined value (the phase difference is equal to zero in the illustration).

[0052] The time-difference measurement units **151, 151'** of the base station controller **1** detect the multiframe timing of the signal S received from the base stations **2, 3** and measure the time difference T between the multiframe timing of the signal S and the multiframe timing of the transmitted signal P. Since the measurement resolution is too low when using the clock (e.g., 1544 kHz) of the transmission line, the high-frequency clock (e.g., 19.6608 MHz), used in the base station controller **1**, is employed to improve the resolution. The time difference T measured by the time-difference measurement units **151, 151'** is the round-trip delay time associated with the transmission line. Accordingly, the correction information generators **152, 152'** adopt half of this value as the one-way transmission delay time, create time correction information using this transmission delay time and output the time correction information. It should be noted that when the phase offset between the signals Q and R is not zero, then half of a value obtained by subtracting this phase offset from the above-mentioned time difference will serve as the one-way transmission delay time.

[0053] Next, by using the synchronizing code MS of the multiframe at the beginning of an interval as the reference, the items of time information (reference time) and time correction information are sent to the base stations **2, 3** on a per-interval basis (i.e., every 1000 multiframes). The time information indicates the starting time of the next interval; for example, the time information in the interval **1** of **FIG. 4**, indicates the starting time of the interval **2**. The time correction information indicates the time D, which is obtained by subtracting T/2, namely the one-way transmission delay time, from the interval time (=3 s). In other words, D [=(3 s)−(one-way transmission delay time)] is the time correction information. The multiplexers **142, 142'** send the time information (the starting time of the next interval) and the time correction information to the base stations **2, 3** using the synchronizing code MS of the multiframe at the beginning of the interval. Though the details will be described later, the multiplexers actually send the time information and time correction information using the synchronizing codes MS of the leading **11** multiframes of an interval.

[0054] Thus, when the multiframe at the beginning of interval **1** is sent to the base stations **2, 3**, the latch **252** of the time management unit **25** latches the time information (the starting time of the next interval) and the delay circuit **253** monitors whether the time D indicated by the time correction information has elapsed. If the elapsed time is equal to the time D, then the delay circuit **253** loads the starting time of interval **2** into the time counter **254**. As a result, the time of the base stations **2, 3** will coincide with the reference time of the base station controller **1**. By counting time using the 19.6608-MHz clock, it is possible to keep track of the same absolute time as that of the base station controller **1**.

(f) Signal Format

[0055] **FIG. 5** is a diagram useful in describing the format of signals sent and received between the base station controller **1** and base stations **2, 3**, and **FIG. 6** is a diagram useful in describing time information and time correction information based upon data bits (DL bits).

[0056] As shown in **FIG. 5**, the signal frame length is 125 μS,, the 3-ms multiframe is formed by 24 frames, and interval of 3 s is formed by 1000 multiframes. One frame is composed of an F bit (one bit) and 24 time slots, and each time slot is composed of eight bits. The base station controller **1** and base stations **2, 3** transform the original communication signals (a voice signal, call control signal, etc.) into ATM cells, imbed the cells successively into the areas of TS1-TS24 (24 time slots) of this format and send the cells to the apparatus of the other party.

[0057] The 24 F bits of the 24 frames that constitute one multiframe form (1) synchronizing bits FAS for the multiframe, (2) DL bits for 4-kbps data and (3) CRC bits for performance monitoring. The multiframe synchronizing bits FAS are composed of six bits (001011), the data bits DL of 12 bits (m_1 to m_{12}) and the performance monitoring bits CRC of 6 bits (e_1 to e_6).

[0058] The time information and time correction information is sent using the DL bits of 11 multiframes at the beginning of an interval. The demarcation of the 1000 multiframes (one interval) is indicated by m_1, m_2. More specifically, the year, month, day, hour, minute and second of the time information (reference time) are carried by BCD codes using the data bits m_3 to m_{10} of the first through seventh multiframes, and the time correction information is carried by binary codes using the data bits m_3 to m_{10} of the eighth through eleventh multiframes. In regard to the time correction information, a value obtained by counting at the 19.6608-MHz clock is carried in the form of binary codes. That is, when one-way transmission delay time is 100 ms=1,966,080 clock pulses, time correction information will be D=3 s−100 ms=2.9 s=57,016,320 clock pulses and values b_{31}-b_0 obtained by the binary coding of 57,016,320 are carried as the data bits of the eighth to eleventh multiframes. It should be noted that m_{11}, m_{12} of all multiframes and data bits m_2 to m_{10} of the 12th to 1000th multiframes are "undefined". Here they are assumed to be "0" by way of example.

(g) Modification

[0059] In FIG. 4, synchronization of time is performed by adopting the starting time of the next interval as the time information and sending the time D obtained by subtracting the transmission delay time from the interval length to the base stations 2, 3 as the time correction information. However, it is also possible to adopt an arrangement of the kind described below.

[0060] Specifically, in this modification, the base station controller 1 adopts the starting time of the current interval as time information and sends the transmission delay time to the base stations 2, 3 as the time correction information. Upon receiving this information, the base stations 2, 3 correct the current time (starting time of the current interval+transmission delay time) immediately to thereby synchronize the time to the reference time of the base station controller 1.

[0061] Further, the base station controller 1 sends the time obtained by adding the transmission delay time to the starting time of the current interval (namely starting time of the current interval+transmission delay time) to the base stations 2, 3 as the time reference information. The base stations 2, 3 correct their own time to the time indicated by the received time reference information, whereby the base stations 2, 3 are synchronized to the reference time of the base station controller 1.

[0062] Thus, in accordance with the present invention as described above, only a base station controller is provided with a GPS receiver, time reference information is sent from the base station controller to base stations and the time of each base station is synchronized to the time of the base station controller. As a result, the time of all base stations can be synchronized to the absolute time through an inexpensive arrangement. In addition, signals to be transmitted from the base stations can be synchronized to one another.

[0063] Further, in accordance with the present invention, reference time specifying data and time correction data for each base station are transmitted periodically from the base station controller to each of the base stations as time reference information, and each base station uses the reference time specifying data and time correction data to correct its own time to the time of the base station controller. As a result, the time in each base station can be synchronized momentarily even if a base station re-synchronizes for some reason or recovers after the occurrence of a failure, and the signal to be transmitted can be synchronized with transmitted signals from other base stations. This contributes to a reduction in the cost of the overall CDMA system and to a shortening of failure recovery time.

[0064] In accordance with the present invention, the base station controller measures the transmission delay time from the base station controller to a base station based upon the frame timing of a signal transmitted to the base station and the frame timing of a signal received from the base station, creates time correction data using this transmission delay time and transmits the time correction data to each base station. Each base station then corrects its own time to that of the base station controller using the reference time specifying data and time correction data. This makes it possible to accurately synchronize the time of the base station to the time of the base station controller.

[0065] In accordance with the present invention, the base station controller measures the transmission delay time from the base station controller to a base station based upon the frame timing of a signal transmitted to the base station and the frame timing of a signal received from the base station, adds this transmission delay time to the reference time to create the time reference information and then transmits the time reference information to each base station. Each base station then synchronizes its own time to that of the base station controller based upon the time reference information that has been received. This also makes it possible to accurately synchronize the time of the base station to the time of the base station controller.

[0066] In accordance with the present invention, the base station controller measures, every n frames, the transmission delay time from the base station controller to a base station based upon the frame timing of a signal transmitted to the base station and the frame timing of a signal received from the base station, adopts a reference time that follows n frames as the reference time specifying data, adopts time obtained by subtracting the transmission delay time from the period of n frames as the time correction data, and transmits this reference time specifying data and time correction data to each base station. Upon elapse of time indicated by the time correction data, each base station makes its own time agree with the reference time indicated by the reference time specifying data. This also makes it possible to accurately synchronize the time of the base station to the time of the base station controller.

[0067] As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

What is claimed is:

1. A time synchronization method for synchronizing the time of a plurality of base stations in a CDMA system and the time of a base station controller that controls each of these base stations, comprising the steps of:

providing the base station controller with a GPS receiver for receiving a signal from GPS satellites and generating a reference time based upon the received signal;

adopting the reference time generated by the GPS receiver as the time of the base station controller, creating time reference information based upon this time and sending the time reference information to each base station; and

in each base station, synchronizing the time of each base station to the that of the base station controller based upon the time reference information received by each base station.

2. The method according to claim 1, further comprising the step of periodically transmitting, to each base station as the time reference information, reference time specifying data and time correction data for each base station.

3. The method according to claim 2, wherein each base station synchronizes its own time to that of the base station controller based upon the reference time specifying data and the time correction data received from said base station controller.

4. The method according to claim 2, further comprising the steps of:

providing in each base station a phase offset (inclusive of a phase offset of zero) between frame timing of a receiving signal from the base station controller and frame timing of a transmitting signal to the base station controller;

in the base station controller, measuring a transmission delay time from the base station controller to the base station based upon frame timing of a transmitting signal to the base station, frame timing of a receiving signal from the base station and said phase offset;

transmitting the transmission delay time from the base station controller to each base station as the time correction data; and

in each base station, correcting the time of each base station to the that of the base station controller based upon the reference time specifying data and the time correction data received from said base station controller.

5. The method according to claim 2, further comprising the steps of:

providing in each base station a phase offset (inclusive of a phase offset of zero) between frame timing of a receiving signal from the base station controller and frame timing of a transmitting signal to the base station controller;

in the base station controller, measuring, every n frames, a transmission delay time from the base station controller to the base station based upon frame timing of a transmitting signal to the base station, frame timing of a receiving signal from the base station and said phase offset; and

adopting a reference time that follows n frames as the reference time specifying data, adopting correction information, which is for correcting said reference time that follows the n frames and is based upon the transmission delay time, as the time correction data, and transmitting these items of data from the base station controller to each base station.

6. The method according to claim 5, further comprising the step of each base station making its own time agree with the reference time indicated by the reference time specifying data upon elapse of time indicated by the time correction data after the base station receives the reference time specifying data and the time correction data.

7. The method according to claim 1, further comprising the steps of:

providing in each base station a phase offset (inclusive of a phase offset of zero) between frame timing of a receiving signal from the base station controller and frame timing of a transmitting signal to the base station controller;

in the base station controller, measuring a transmission delay time from the base station controller to the base station based upon frame timing of a transmitting signal to the base station, frame timing of a receiving signal from the base station and said phase offset; and

adding this transmission delay time to the reference time to create the time reference information and transmitting this time reference information to each base station;

wherein each base station synchronizes its own time to that of the base station controller based upon the time reference information it has received.

* * * * *

US006009086A

United States Patent [19]

Freeburg et al.

[11] Patent Number: 6,009,086

[45] Date of Patent: Dec. 28, 1999

[54] **POWER CONTROL OF A REMOTE STATION OF A RADIO COMMUNICATIONS SYSTEM**

[75] Inventors: **Thomas A. Freeburg**, Arlington Heights, Ill.; **Daniel B. Grossman**, Norwood, Mass.; **Paul Odlyzko**, Arlington Heights, Ill.

[73] Assignee: **Motorola, Inc**, Schaumburg, Ill.

[21] Appl. No.: **09/215,729**

[22] Filed: **Dec. 18, 1998**

Related U.S. Application Data

[62] Division of application No. 08/615,381, Mar. 14, 1996, Pat. No. 5,940,381.

[51] **Int. Cl.**[6] **H04Q 7/00**; H04L 12/28

[52] **U.S. Cl.** **370/331**; 370/395

[58] **Field of Search** 370/331, 330, 370/335, 332, 323, 337, 350, 395, 397; 455/502, 524, 552, 436, 437, 522

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,428,820	6/1995	Okada et al.	455/522
5,434,853	7/1995	Hemmady et al. .	
5,434,859	7/1995	Levardon .	
5,440,561	8/1995	Werronen	370/337
5,528,583	6/1996	Acampora et al.	370/397
5,590,125	12/1996	Acampora et al. .	
5,633,868	5/1997	Baldwin et al.	370/397
5,638,371	6/1997	Raychaudhuri et al. .	
5,640,414	6/1997	Blakeney, II et al.	375/200
5,648,969	7/1997	Pasternak et al. .	
5,659,544	8/1997	La Porta et al. .	
5,666,349	9/1997	Petri .	
5,678,227	10/1997	Connell et al.	370/311

FOREIGN PATENT DOCUMENTS

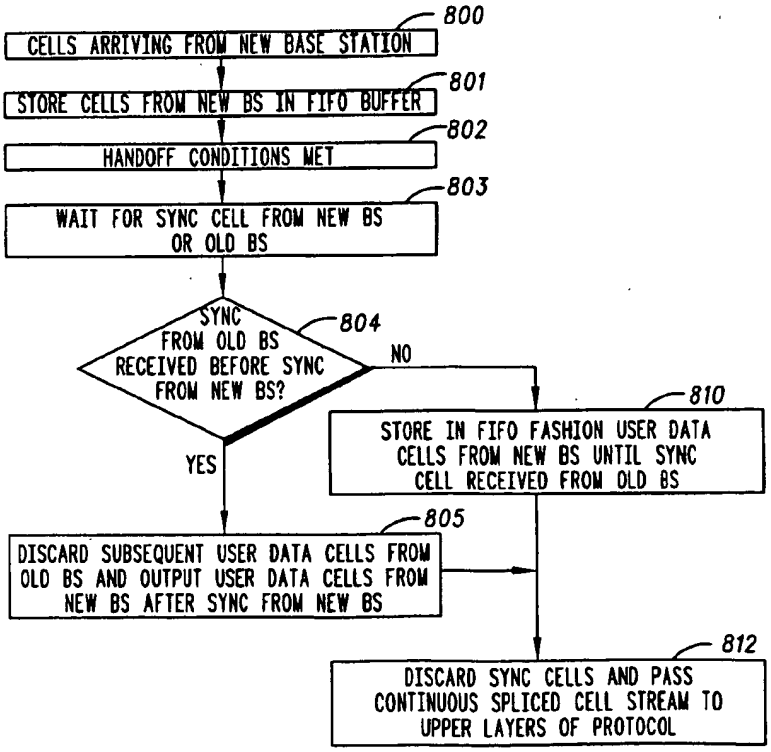
0577322	1/1994	Finland .
0679042	10/1995	United Kingdom .
WO94/28645	12/1994	WIPO .
WO95/32594	11/1995	WIPO .

Primary Examiner—Chau Nguyen
Assistant Examiner—Chiho Andrew Lee

[57] **ABSTRACT**

A radio communications system (**10**) having a remote or mobile station (**30**) and at least two base stations (**13, 14**). ATM radio channels (**31, 32**) are provided between the remote station and base stations. The remote station (**30**) has a logic unit (**520**) for combining cell streams received from the first and second base stations during a handoff from the first base station to the second base station. A receiver in the remote station (**30**) is powered up during first time periods corresponding to physical layer synchronization cells arriving from one base station (**13**) and second time periods corresponding to ATM cells arriving from the other base station. When handoff conditions are met, the receiver is powered up for a third time period longer than the first and second time periods.

4 Claims, 11 Drawing Sheets



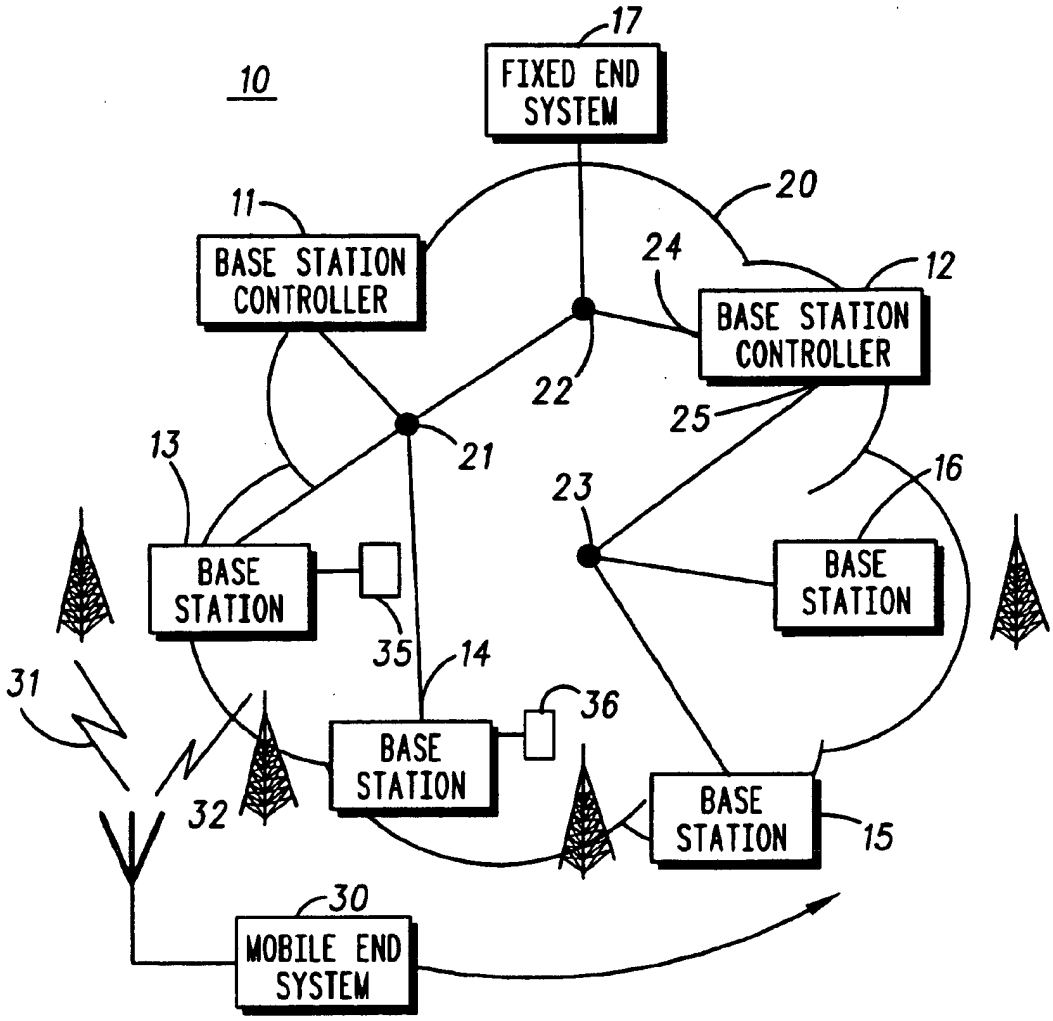

10
17
FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
12
BASE STATION CONTROLLER
22
25
21
13
23
16
BASE STATION
BASE STATION
35
14
31
36
BASE STATION
BASE STATION
15
32
30
MOBILE END SYSTEM

FIG.1

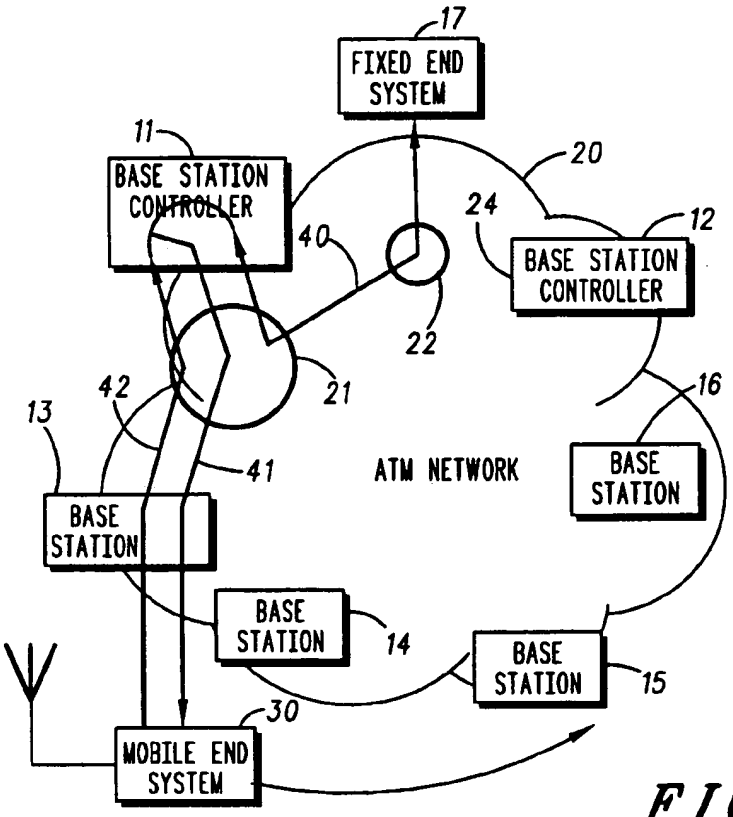

17
FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
12
BASE STATION CONTROLLER
40
22
21
42
16
13
41
ATM NETWORK
BASE STATION
BASE STATION
BASE STATION
14
BASE STATION
15
30
MOBILE END SYSTEM

FIG. 2

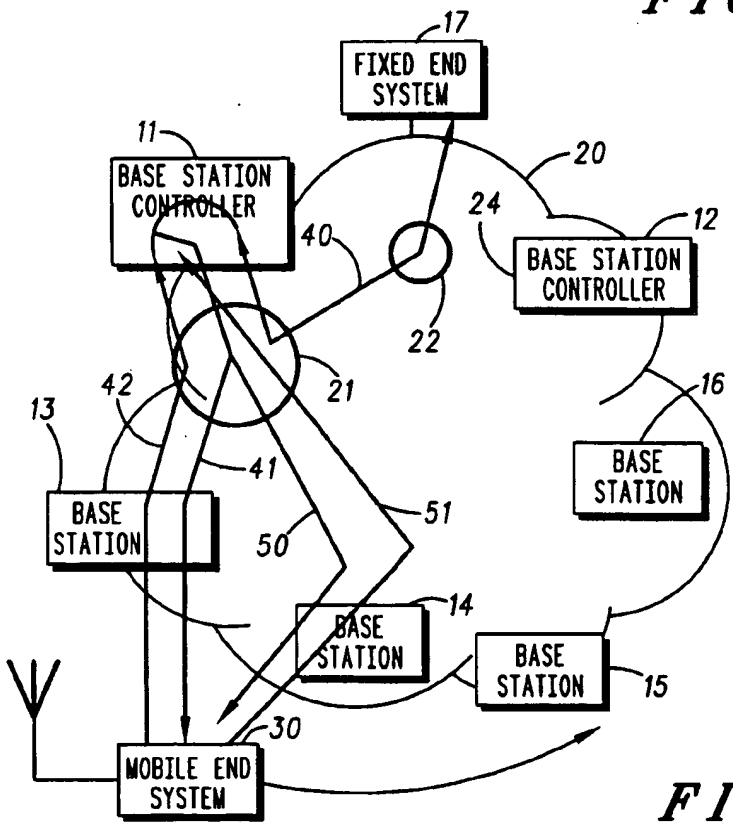

17
FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
12
BASE STATION CONTROLLER
40
22
21
42
16
13
41
BASE STATION
51
50
BASE STATION
14
BASE STATION
BASE STATION
15
30
MOBILE END SYSTEM

FIG. 3

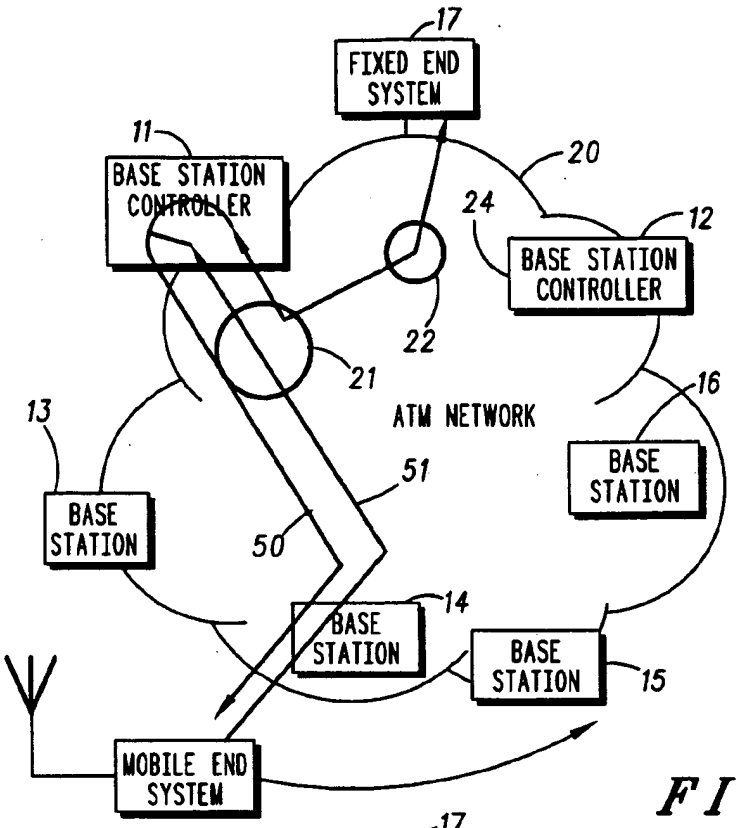

17
FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
12
BASE STATION CONTROLLER
22
21
ATM NETWORK
16
13
51
BASE STATION
BASE STATION
50
14
BASE STATION
BASE STATION
15
MOBILE END SYSTEM

FIG. 4

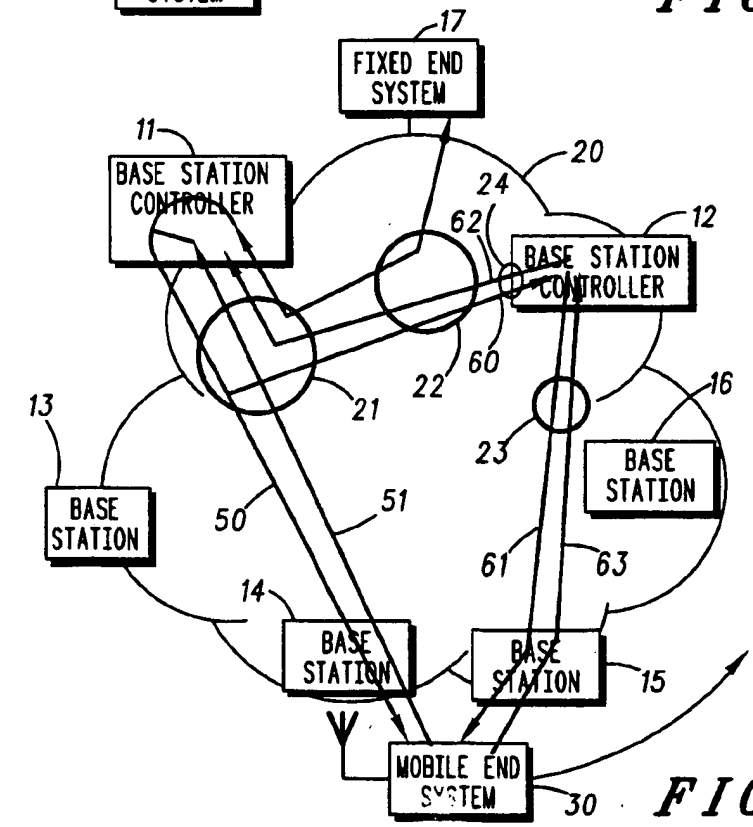

17
FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
62
12
BASE STATION CONTROLLER
22
60
21
16
13
23
BASE STATION
BASE STATION
50
51
61
63
14
BASE STATION
BASE STATION
15
MOBILE END SYSTEM
30

FIG. 5

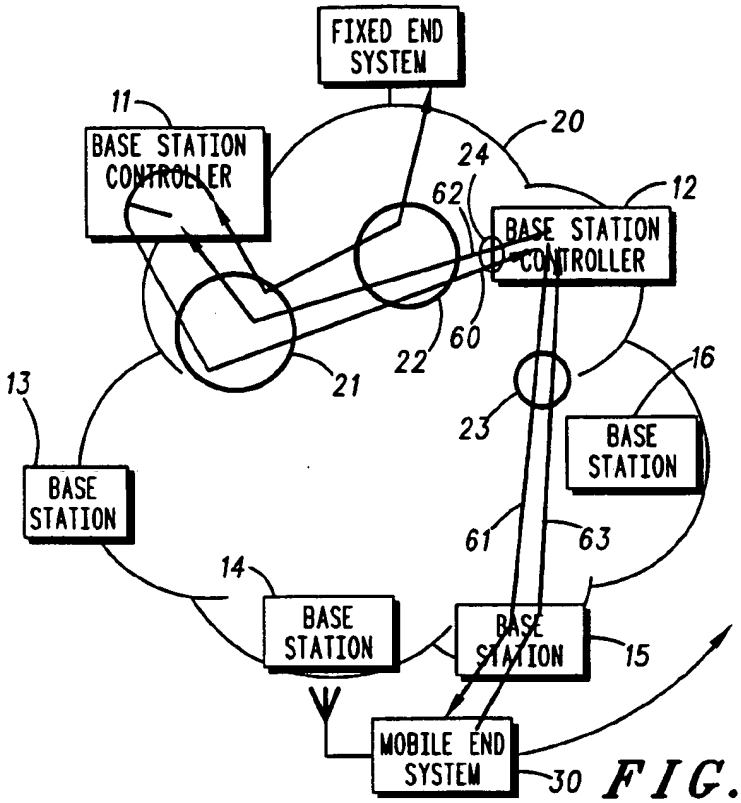
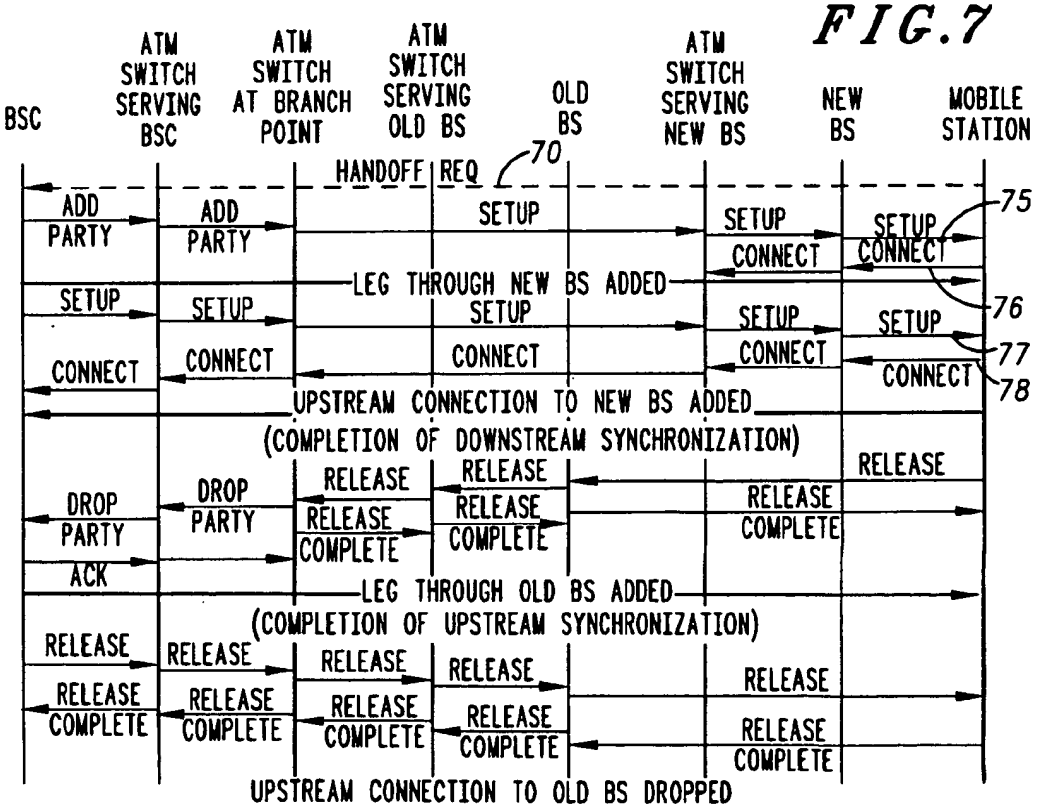

FIXED END SYSTEM
11
BASE STATION CONTROLLER
20
24
62
12
BASE STATION CONTROLLER
60
22
21
16
13
23
BASE STATION
BASE STATION
61
63
14
BASE STATION
BASE STATION
15
MOBILE END SYSTEM
30

FIG.6

FIG.7


BSC
ATM SWITCH SERVING BSC
ATM SWITCH AT BRANCH POINT
ATM SWITCH SERVING OLD BS
OLD BS
ATM SWITCH SERVING NEW BS
NEW BS
MOBILE STATION
HANDOFF REQ
70
ADD PARTY
SETUP
CONNECT
75
LEG THROUGH NEW BS ADDED
76
77
78
UPSTREAM CONNECTION TO NEW BS ADDED
(COMPLETION OF DOWNSTREAM SYNCHRONIZATION)
DROP PARTY
ACK
RELEASE
RELEASE COMPLETE
LEG THROUGH OLD BS ADDED
(COMPLETION OF UPSTREAM SYNCHRONIZATION)
UPSTREAM CONNECTION TO OLD BS DROPPED

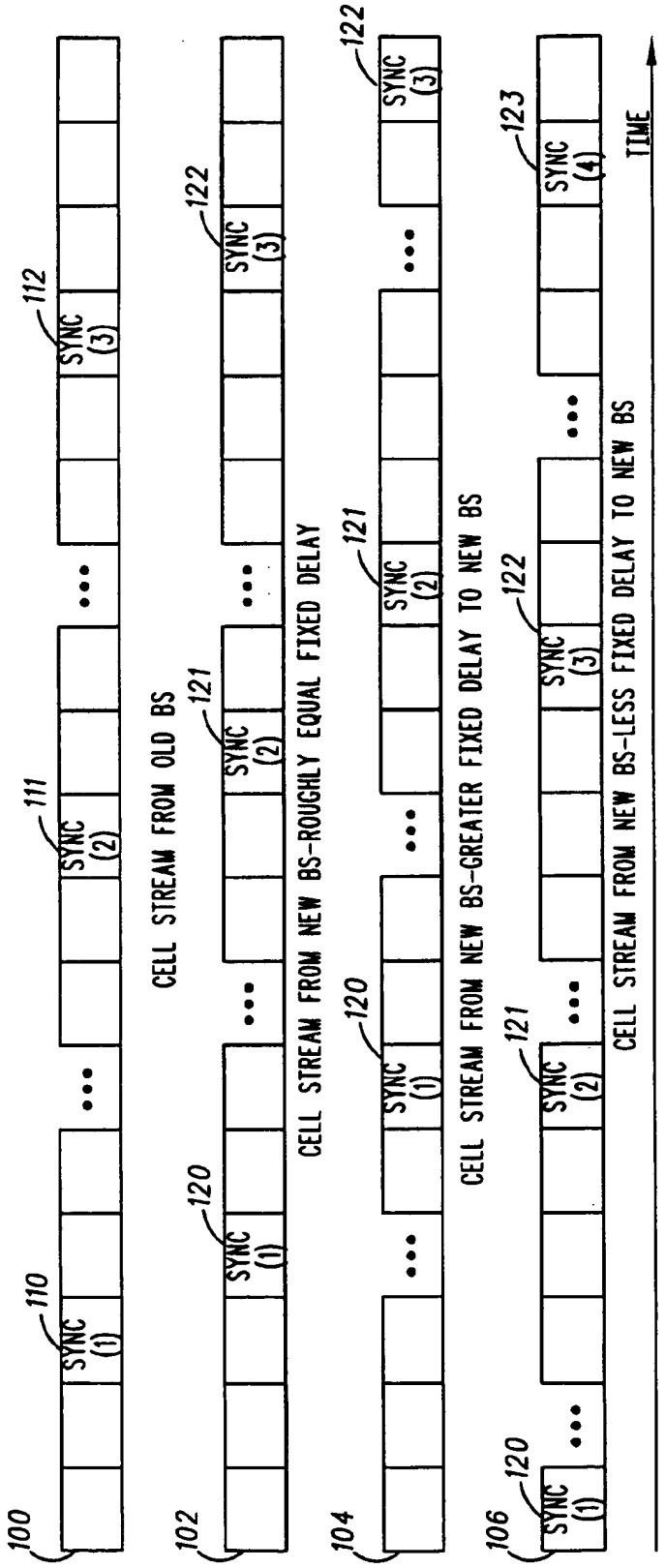

100
102
104
106
110
111
112
120
121
122
123
SYNC (1)
SYNC (2)
SYNC (3)
SYNC (4)
CELL STREAM FROM OLD BS
CELL STREAM FROM NEW BS-ROUGHLY EQUAL FIXED DELAY
CELL STREAM FROM NEW BS-GREATER FIXED DELAY TO NEW BS
CELL STREAM FROM NEW BS-LESS FIXED DELAY TO NEW BS
TIME

FIG. 8

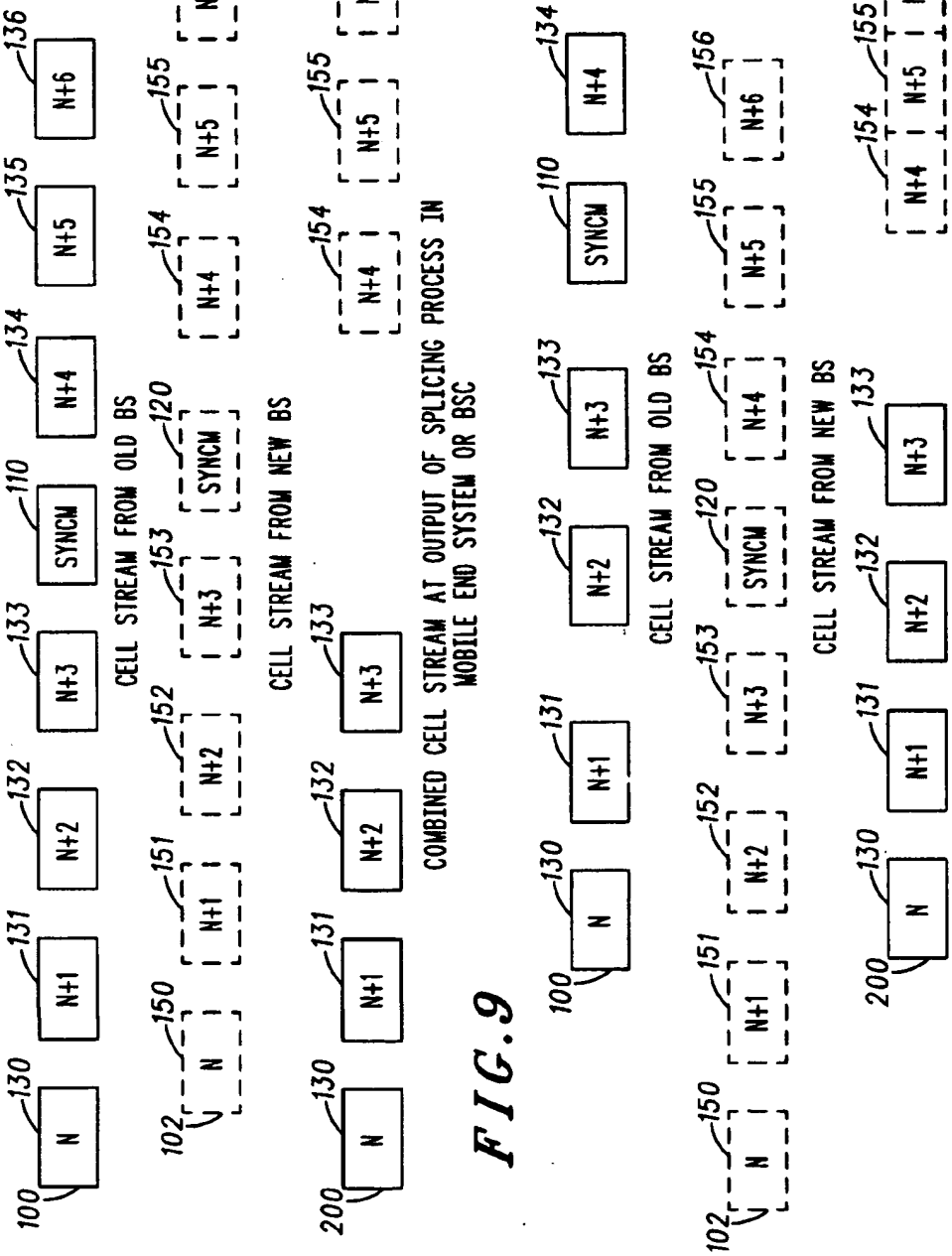

100
130
N
131
N+1
132
N+2
133
N+3
110
SYNCM
134
N+4
135
N+5
136
N+6
102
150
N
151
N+1
152
N+2
153
N+3
120
SYNCM
154
N+4
155
N+5
156
N+6
157
N+7
CELL STREAM FROM OLD BS
CELL STREAM FROM NEW BS
COMBINED CELL STREAM AT OUTPUT OF SPLICING PROCESS IN MOBILE END SYSTEM OR BSC
200
130
N
131
N+1
132
N+2
133
N+3
154
N+4
155
N+5
156
N+6
157
N+7

FIG.9

100
130
N
131
N+1
132
N+2
133
N+3
110
SYNCM
134
N+4
135
N+5
102
150
N
151
N+1
152
N+2
153
N+3
120
SYNCM
154
N+4
155
N+5
156
N+6
157
N+7
CELL STREAM FROM OLD BS
CELL STREAM FROM NEW BS
200
130
N
131
N+1
132
N+2
133
N+3
154
N+4
155
N+5
156
N+6
157
N+7
COMBINED CELL STREAM AT OUTPUT OF SPLICING PROCESS IN MOBILE END SYSTEM OR BSC

FIG.10

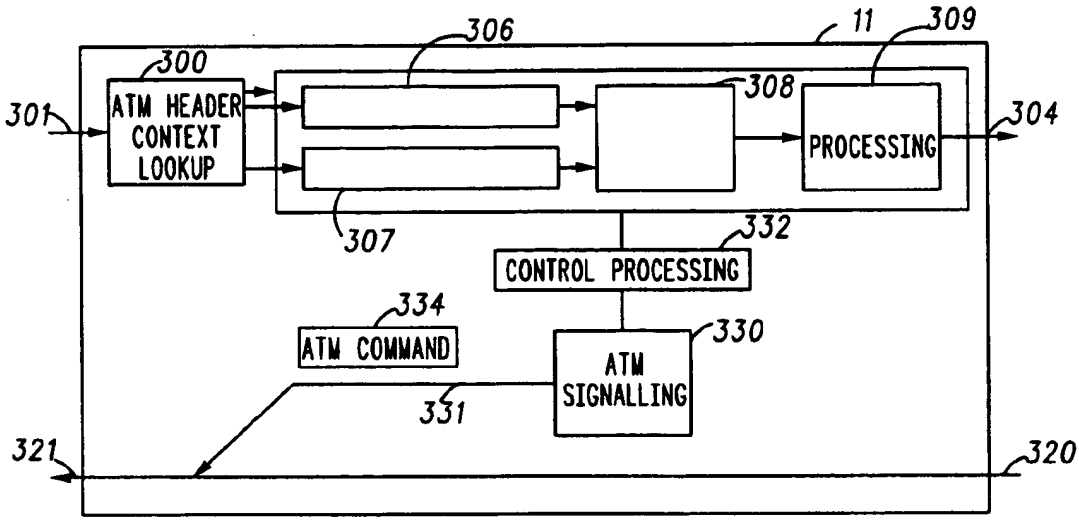

306
11
309
300
308
301
ATM HEADER CONTEXT LOOKUP
PROCESSING
304
307
332
CONTROL PROCESSING
334
330
ATM COMMAND
ATM SIGNALLING
331
321
320

FIG.11

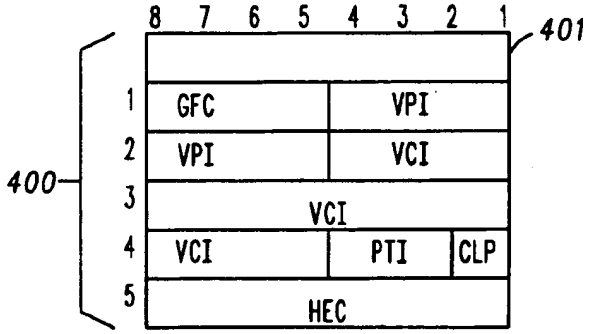

8 7 6 5 4 3 2 1
401
1 GFC VPI
2 VPI VCI
3 VCI
4 VCI PTI CLP
5 HEC
400

FIG.12

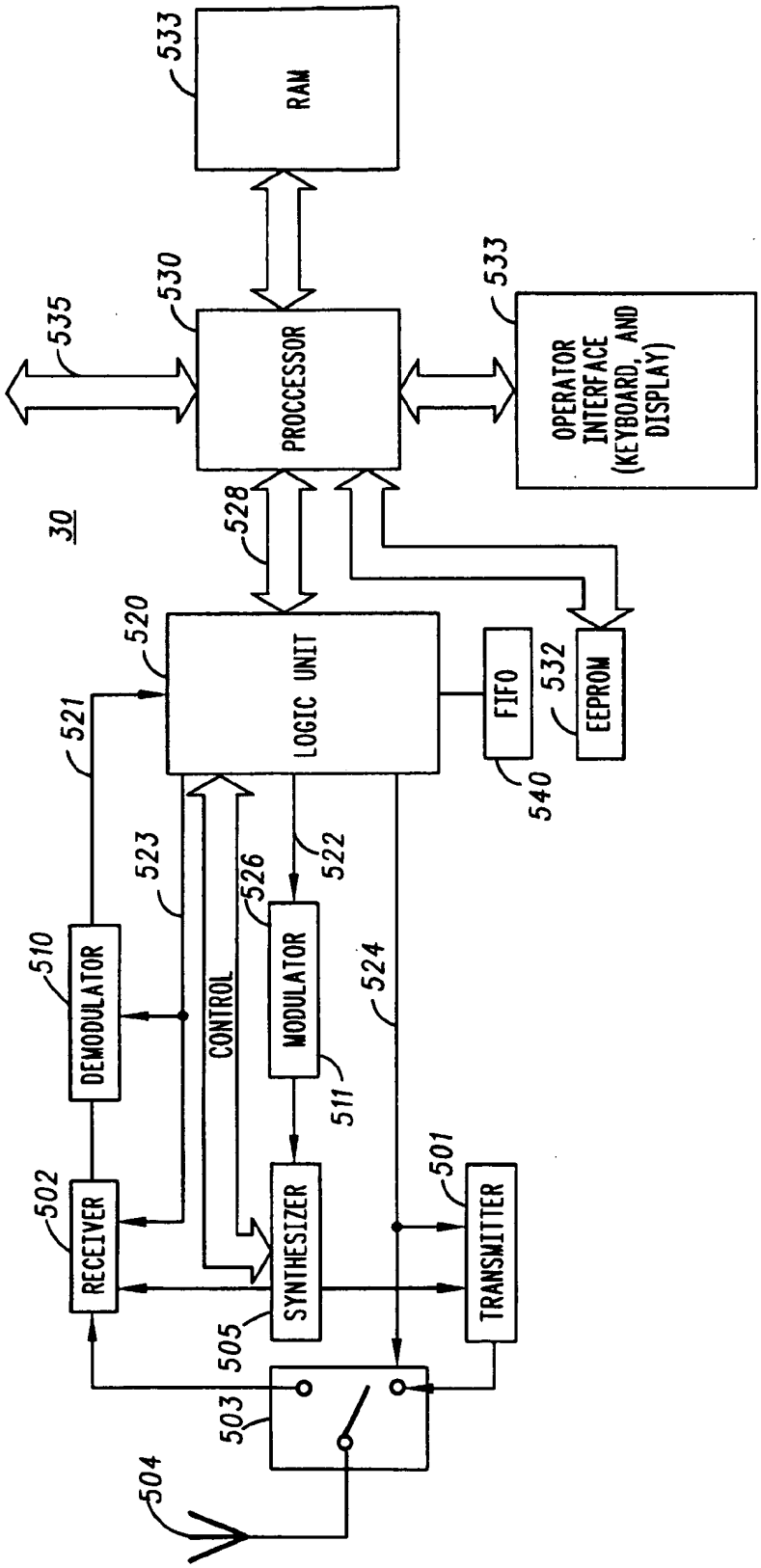

533
RAM
530
PROCCESSOR
535
533
OPERATOR INTERFACE (KEYBOARD, AND DISPLAY)
30
528
520
LOGIC UNIT
FIFO
532
EEPROM
540
521
523
522
526
510
DEMODULATOR
CONTROL
MODULATOR
524
511
501
502
RECEIVER
SYNTHESIZER
TRANSMITTER
505
503
504

FIG.13

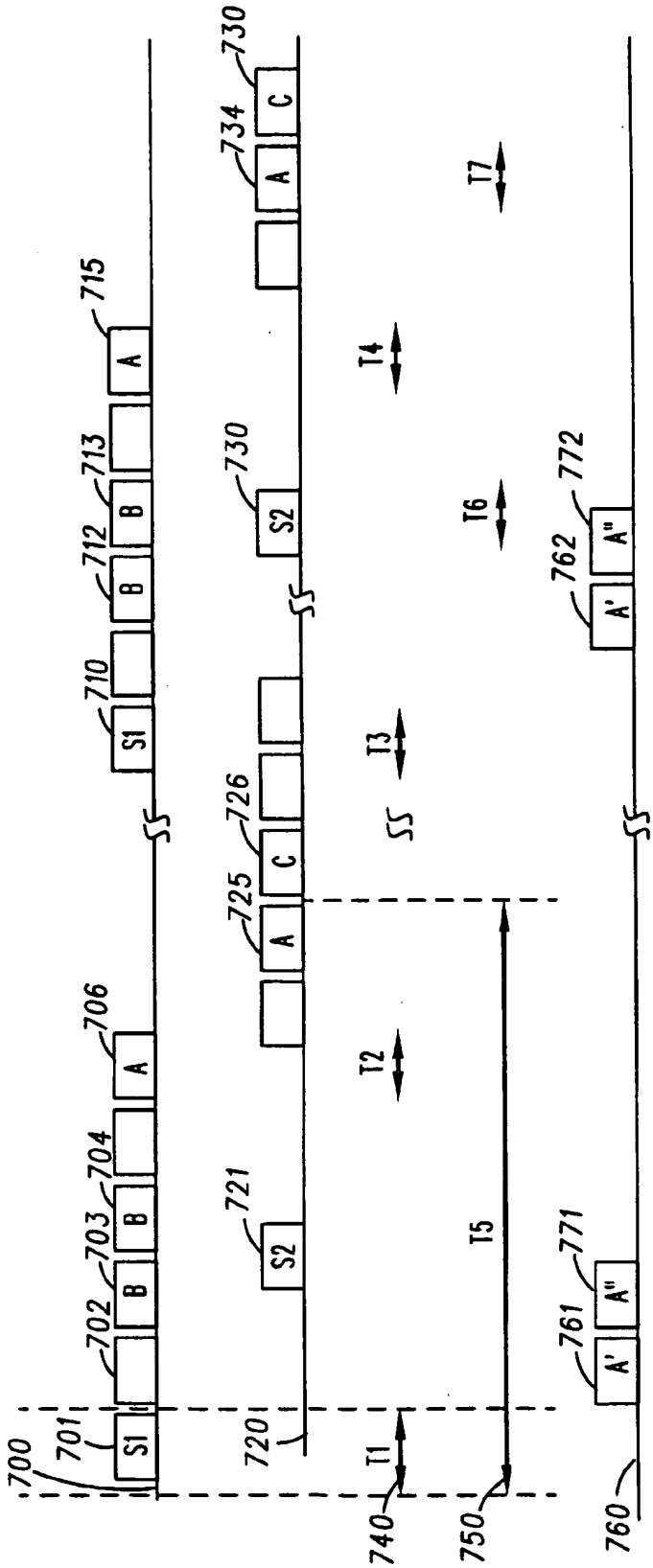

700
701
S1
702
B
703
B
704
706
A
710
S1
712
B
713
B
715
A
720
721
S2
725
A
726
C
730
S2
730
734
A
C
740
750
760
761
A'
771
A"
762
A'
772
A"
T1
T2
T3
T4
T5
T6
T7

FIG.14

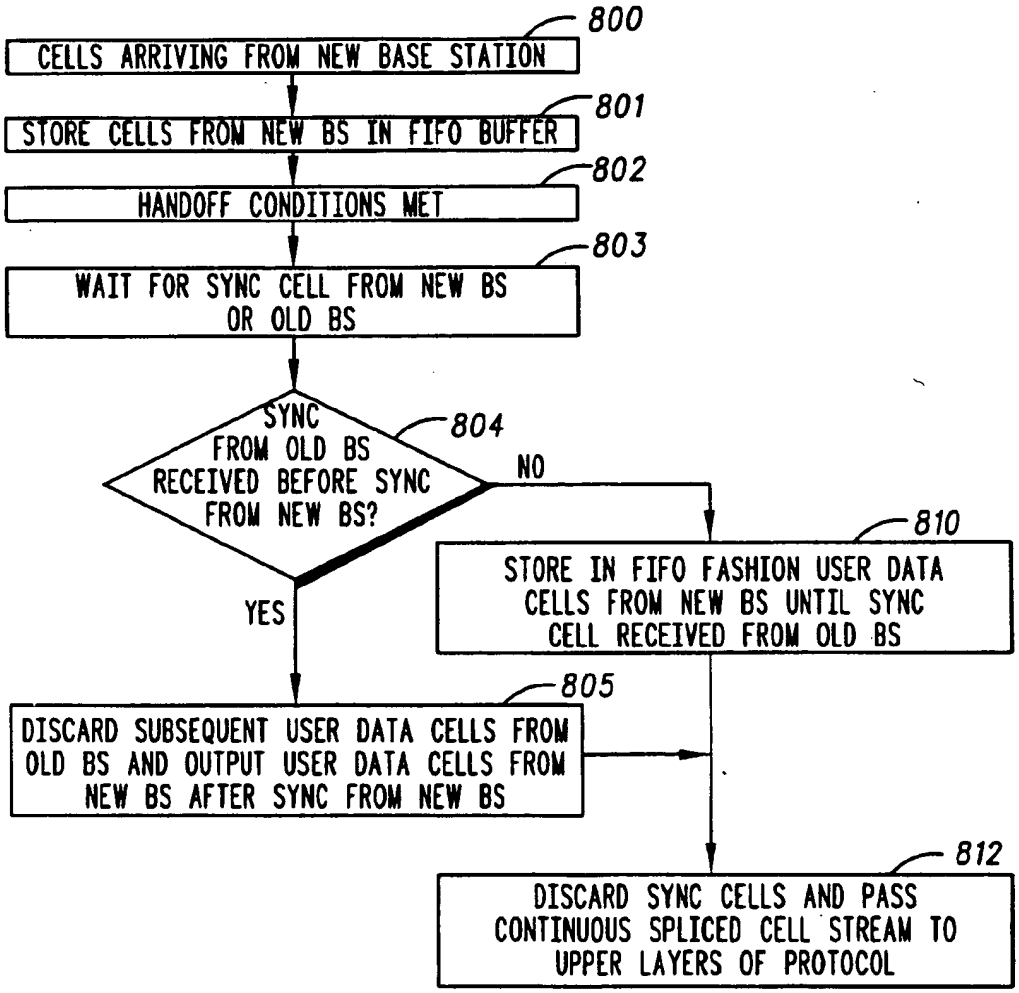

800
CELLS ARRIVING FROM NEW BASE STATION
801
STORE CELLS FROM NEW BS IN FIFO BUFFER
802
HANDOFF CONDITIONS MET
803
WAIT FOR SYNC CELL FROM NEW BS OR OLD BS
804
SYNC FROM OLD BS RECEIVED BEFORE SYNC FROM NEW BS?
NO
YES
810
STORE IN FIFO FASHION USER DATA CELLS FROM NEW BS UNTIL SYNC CELL RECEIVED FROM OLD BS
805
DISCARD SUBSEQUENT USER DATA CELLS FROM OLD BS AND OUTPUT USER DATA CELLS FROM NEW BS AFTER SYNC FROM NEW BS
812
DISCARD SYNC CELLS AND PASS CONTINUOUS SPLICED CELL STREAM TO UPPER LAYERS OF PROTOCOL

FIG.15

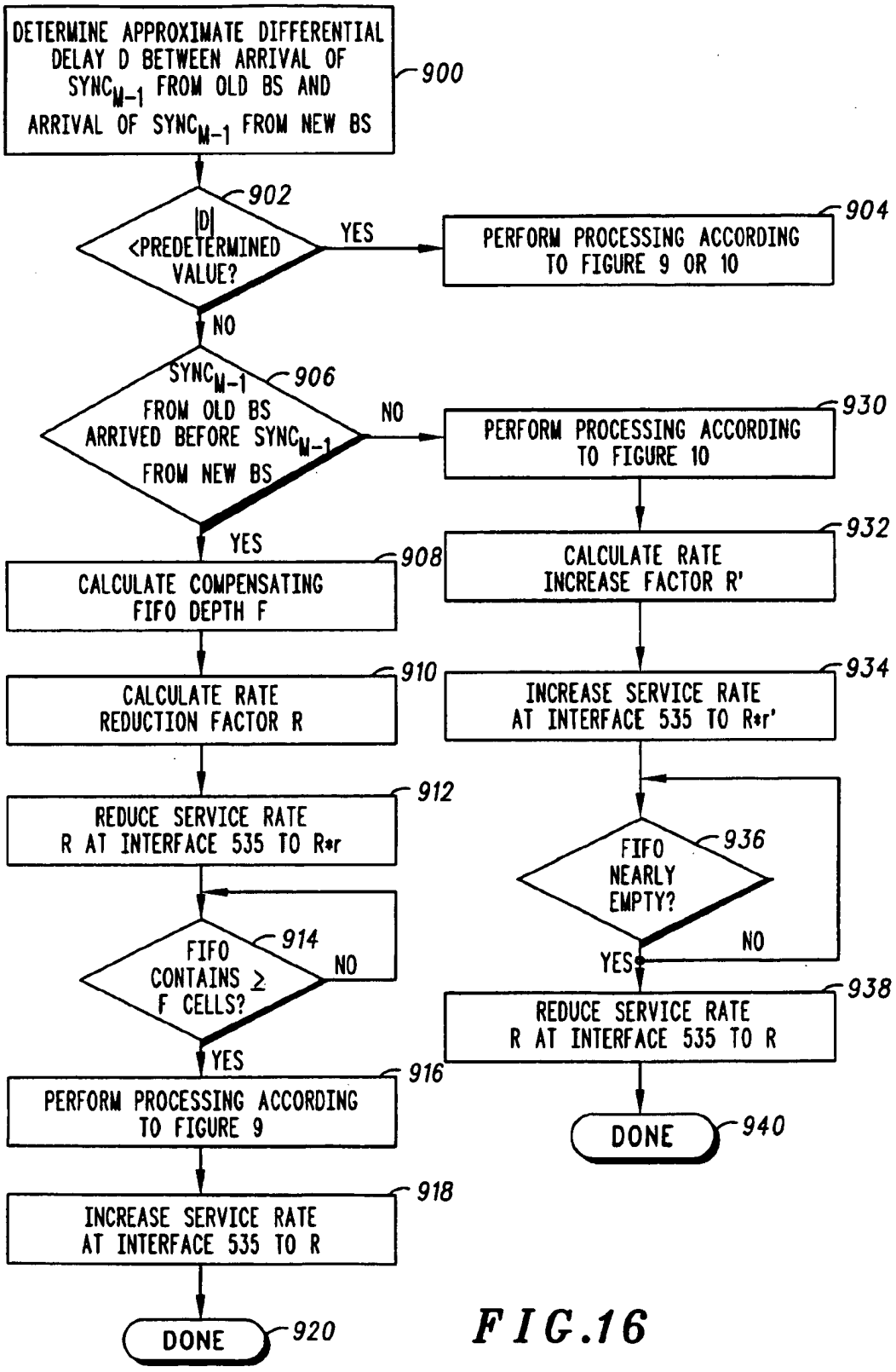

DETERMINE APPROXIMATE DIFFERENTIAL DELAY D BETWEEN ARRIVAL OF SYNC$_{M-1}$ FROM OLD BS AND ARRIVAL OF SYNC$_{M-1}$ FROM NEW BS
900
|D| <PREDETERMINED VALUE?
902
YES
PERFORM PROCESSING ACCORDING TO FIGURE 9 OR 10
904
NO
SYNC$_{M-1}$ FROM OLD BS ARRIVED BEFORE SYNC$_{M-1}$ FROM NEW BS
906
NO
PERFORM PROCESSING ACCORDING TO FIGURE 10
930
YES
CALCULATE COMPENSATING FIFO DEPTH F
908
CALCULATE RATE REDUCTION FACTOR R
910
REDUCE SERVICE RATE R AT INTERFACE 535 TO R*r
912
FIFO CONTAINS ≥ F CELLS?
914
NO
YES
PERFORM PROCESSING ACCORDING TO FIGURE 9
916
INCREASE SERVICE RATE AT INTERFACE 535 TO R
918
DONE
920
CALCULATE RATE INCREASE FACTOR R'
932
INCREASE SERVICE RATE AT INTERFACE 535 TO R*r'
934
FIFO NEARLY EMPTY?
936
NO
YES
REDUCE SERVICE RATE R AT INTERFACE 535 TO R
938
DONE
940

FIG.16

POWER CONTROL OF A REMOTE STATION OF A RADIO COMMUNICATIONS SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is divided out of application Ser. No. 08/615,381 filed on Mar. 14, 1996 (now U.S. Pat. No. 5,940,381).

FIELD OF THE INVENTION

This invention relates to a wireless communications system utilizing asynchronous transfer mode (ATM communications) and it relates to remote station (generically referred to as a 'mobile station' though not necessarily mobile) for operation in such a system and, separately, a base station controller and a method of operation.

BACKGROUND OF THE INVENTION

In the modern telecommunications world, voice communications continue to be a popular mode of communication, but new services like video telephony, high speed data and short message services continue to expand on existing services. The arrival of new telecommunications services generates new requirements for telecommunications networks. New telecommunications techniques (transfer modes) are required and offer possible advantages compared to existing techniques. Traditional transfer modes for wired communications are circuit switching, familiar in classical telephone services, and packet switching, familiar in telegraphy and modem short message service and data systems.

Asynchronous transfer mode (ATM) is a mode of fast packet switching which allows systems to operate at a much higher rate than traditional packet switching systems. Features which characterize ATM communications are: the ability for asynchronous operations between a sender clock and a receiver dock; transmission "cells" of pre-defined sizes; and addressing carried out in a fixed size header (that is not but time, frame position or other fixed characteristic). ATM communication is sometimes also referred to as asynchronous time division (ATD) communications.

Asynchronous transfer mode (ATM) is a mode of fast packet switching which facilitates switching systems that operate at a much higher rate than traditional packet switching systems. Features which characterize ATM communications are: the ability for asynchronous operations between a sender clock and a receiver clock; the concept of a "virtual connection" which is established for the lifetime of an information flow that comprises part or all of the communication; transmission "cells" of a fixed, standardized size; and connection identification carried in a fixed size header (that is not by time, frame position or other fixed characteristic). ATM communication is sometimes also referred to as asynchronous time division (ATD) communications. Other features of ATM communications are notions of a "service category", "traffic contract" and Quality of Service objectives that apply to the virtual connection. The expression "virtual connection" here is used to refer a virtual path and virtual circuit pair and "virtual connection identifier" means either a virtual path identifier (VPI) or a virtual circuit identifier (VCI) or both.

ATM communication has proven useful in high-value point-to-point land-line communication, for example, satellite links and undersea cables. ATM allows multiple simultaneous circuits, sometimes referred to as virtual circuits (VCs), to be established from end to end along the link.

European Patent No. EP0679042 of Roke Manor Research describes a mobile communications network with ATM as the transfer mode used in the switching infrastructure and describes steps to be taken in the mobile network switching infrastructure when a mobile terminal changes affiliation from one base station to another base station, as in a conventional handoff operation and when a mobile terminal communicates simultaneously through more than one base station. The transfer mode of the radio link is not described. International Patent Application No. WO94/28645 of The Trustees of Columbia University in the City of New York also addresses the use of ATM in a mobile communications system switching network and addresses distributed call set-up and rerouting in a mobile ATM based system with ATM switches.

A mobile communications network consists of a number of mobile end systems, a number of base stations, and a number of base station controllers, where the base stations and base station controllers are interconnected using an Asynchronous Transfer Mode (ATM) network. When a mobile end system moves from radio site (or "cell" or "zone") to another, it is necessary to execute a handoff between the corresponding base stations.

The standardized ATM architecture prohibits any ATM network (including a wireless ATM network) from misordering or duplicating ATM user data cells. In general, ATM networks should lose (i.e. by discarding) few, or preferably no, ATM user data cells at any time, including during handoff. Further, the ATM service architecture distinguishes between 'real time' and 'non-real time' service categories. In real time service categories, cell delay variation (CDV—the variability in the pattern of cell arrival events at the output of an ATM connection relative to the pattern of corresponding events observed at the input of the connection) is an element of quality of service. CDV is negotiated between the end systems (including mobile end systems) and the network (s). If a cell exceeds the agreed CDV, then it either is lost, or becomes useless to the end system when it is delivered; thus, a late cell is treated as if it were lost. Non-real time services are indifferent to CDV, but may be more sensitive to cell discard.

The arrangements described in the above prior art patent application are not optimal in their use of ATM resources in an access network, nor do those arrangements address communication using ATM as the transfer mode over-the-air.

International Patent Application No. WO94/32594 of NTT Mobile Communication Network, Inc. describes a cellular mobile radio communication system soft-handover scheme using code division multiple access (CDMA) where signals transmitted from different base stations are spread with different spread codes and simultaneously received at a mobile station with reception units in correspondence to different base stations. It is described how communication can take place in packets which include a call number, in case the mobile station deals with a plurality of calls, a sequence number and an identification number (ID) for the mobile station. It is explained how the same packet can be received at the mobile station from more than one base station or received at more than one base station from the same mobile station, to provide a reliable diversity handover scheme. The establishment of simultaneous communication through two base stations is described, without the completion of a handover process being described. It must be assumed that the completion of handover complies with pre-existing CDMA soft handover principals. The patent application also mentions that the packet communication scheme can be an ATM scheme.

Attention is turning to the use of ATM for the radio interface transfer mode of wireless communications. There is, for example, a need for wireless users to have access to wired ATM networks and existing ATM systems such as multi-media applications need a wireless platform providing multi-media support. It is also recognized that systems such as universal mobile telephone systems (UMTS) and existing wireless local area networks (LANs) cannot meet all future data user needs. Efforts to date have been in the use of ATM in the wireless extension of fixed infrastructure systems, such as local area networks (LANs) and integrated service data network (ISDN).

For private land mobile networks and cellular radio networks, circuit-switched frequency-division multiple access (FDMA) with or without time division multiple access (TDMA), as well as code division multiple access (CDMA) continue to be the available multiple access schemes for the radio interface. Each of these multiple access schemes has its advantages and disadvantages in different circumstances and the various schemes are generally incompatible with each other.

A mobile radio system is now envisaged using ATM as the transfer mode and using a novel multiple access scheme which has advantages over existing FDMA, TDMA and CDMA multiple access schemes. There is a need for a method of handover in such a novel system.

Glossary of Terms

ATM	Asynchronous Transfer Mode
BS	Base station
BSC	Base station controller
CDV	Cell Delay Variation
CLP	Cell Loss Priority
GFC	Generic Flow Control
HEC	Header Error Control
PTI	Payload Type Identifier
VPI	Virtual Path Identifier
VCI	Virtual Circuit Identifier

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a mobile radio network.

FIGS. **2** through **6** are further block diagrams of the network of FIG. **1** showing a sequence of connection configurations.

FIG. **7** is a ladder diagram showing an exchange of signaling messages for a base station to base station handoff.

FIG. **8** is a time sequence diagram showing the timing relationship of cell streams during different handover scenarios.

FIG. **9** is a time sequence diagram illustrating a splicing operation in a first scenario.

FIG. **10** is a time sequence diagram illustrating a splicing operation in a second scenario.

FIG. **11** is a block diagram of a BSC in accordance with one aspect of the invention.

FIG. **12** is a bit map diagram of an ATM header with physical layer information added.

FIG. **13** is a block diagram of a mobile station.

FIG. **14** is a flow diagram illustrating operations performed by the mobile station of FIG. **13**.

FIG. **15** is a timing diagram illustrating power saving features of the mobile station of FIG. **13**.

FIG. **16** is a flow diagram showing further operations performed by the mobile station of FIG. **13**.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a radio communications system **10**, which comprises a number of base station controllers (BSCs) of which two are shown as BSCs **11** and **12**, each controlling a number of base stations (BSs) **13**, **14**, **15** and **16** by way of example. Each BSCs, e.g. BSC **11** communicates with associated base stations **13** and **14**, with one or more fixed ATM end systems **17** and with other BSCs, e.g. BSC **12**, by means of a fixed ATM network **20**, which is implemented using existing standards and implementation agreements. The fixed ATM network **20** is comprised of a mesh of interconnected ATM nodes, of which three (nodes **21**, **22** and **23**) are shown in FIG. **1** by way of example.

Node **21** is connected to BSC **11** and BSs **13** and **14** and to node **22**. Node **22** is connected to BSC **12**, via a first port **24** of BSC **12**, and fixed to end system **17**. Node **23** is coupled to BSC **12** via a second port **25** of BSC **12** and is coupled to BSs **15** and **16**. Thus different configurations are possible and a node, e.g. node **21**, can pass downstream traffic from the fixed end system **17** to the BSC **11** and from the BSC **11** to a BS **13** while simultaneously passing upstream traffic from a BSC **11** to the BSC **11** and from the BSC 11 to the fixed end system **17**. Alternatively, a BSC, e.g. BSC **12** can effectively divide the network into a sub-network on the mobile side and a sub-network on the fixed side.

In a real system, there will be many more nodes in the network **20** and any given link between the fixed end system and a base station via a BSC may pass through many nodes in sequence.

The network **10** further includes a number of mobile ATM end systems (alternatively "remote stations" and hereafter simply "mobile stations"), which communicate with the base stations by radio. One such mobile station **30** is shown by way of example. An object of end-to-end communication is the establishment of one or more ATM virtual connections between the mobile station **30** and one or more fixed end systems **17**. The mobile end system moves during the lifetime of the ATM connection, moving from the radio cell covered by the first base station to the radio cell covered by the second base station and so on. First ATM radio channel **31** is provided between mobile station **30** and base station **13** and second ATM radio channel **32** is provided between mobile station **30** and base station **14**. First and second ATM radio channels **31** and **32** support communication though ATM cells over a common frequency band and are described in more detail below. Base station **13** has a connection identifier memory **35** and base station **14** has a connection identifier memory **36**.

As the mobile end system travels from radio cell to radio cell in the direction of the arrow, it is desirable that the connection segment between the old base station and the BSC (for inter-base station handoffs), as well as the connection segment between the new anchor BSC and the old BSC (for inter-BSC handoffs) be removed from the connection, so as to release resources and minimize fixed and variable delay. To the extent possible, it is desirable to use existing ATM standards and implementation agreements. In particular, mobile-specific modifications to the fixed ATM network should be avoided.

There is a trade-off to be made with regard to the use of ATM virtual paths (VPs). A VP is an aggregation of virtual circuits, which can be processed by an ATM VP switch as a group rather than individually. If all virtual circuit connections (VCCs) to a single mobile end system are aggregated into a single VP connection, handoffs can be executed on the

aggregate, minimizing processing. However, the service category and quality-of-service provided for the VP are at least as stringent as those for the most sensitive VCC that uses the virtual path connection (VPC), and the traffic contract for the VPC is at least as large as the sum of the traffic contracts for all of the possible VCCs (noting that VCCs can be added after the VPC is established). This approach is more efficient in this respect than arrangements in the prior art.

Although the preferred embodiment of the present invention uses switched VCCs from the BSC to the BS, an alternative embodiment uses switched VPCs (i.e. established on demand using signaling). In this case, there is a VPC for each mobile device. The traffic contract is sufficient to handle only existing VCCs and some additional margin; it can be adjusted as needed during a handoff or by means of signaling renegotiation.

FIGS. **2** through **6** represent a sequence of connection configurations in the system of the preferred embodiment of the present invention, as the mobile end system moves. The heavy lines in each figure show the connection configuration.

A BSC, e.g. BSC **11** in FIG. **2**, is the endpoint of a point-to-point bidirectional virtual circuit connection (VCC) **40**, where the other endpoint of the VCC is the fixed end system **17**. Thus, BSC **11** appears to the ATM network **20** to be an end system. The BSC **11** is also an endpoint of two or more virtual connections, which may be VCCs or virtual path connections (VPCs). One of these virtual connections, which is designated the downstream virtual connection **41**, is a unidirectional point-to-multipoint connection, having its root at the BSC **11**, such that ATM cells flow from the BSC to all BSs that are presently joined to the downstream virtual connection. The other virtual connection, which is designated the upstream virtual connection **42**, is a unidirectional point-to-point connection, such that ATM cells flow from a single base station **13** to the BSC **11**. Point-to-point and point-to-multipoint unidirectional virtual connections and the means for signaling to obtain them are defined in the ATM standards. The BSC **11** splits the two directions of the connection between itself and the fixed end system by switching cells received from the fixed end system **17** to the downstream virtual connection **41** and by further switching cells received on the upstream virtual connection **42** towards the fixed end system.

FIG. **2** shows the initial configuration of ATM connections. An end-to-end communication has been established by means known in the art, including establishment of the upstream and downstream virtual connections, by means of standardized ATM signaling protocols. The downstream virtual connection **41** has only one leg, so is indistinguishable in the figure from a point-to-point connection. Thus, cells sent by the fixed ATM end system **17** are forwarded by the BSC **11** to the base station **13** serving the mobile station **30**, and cells sent by the mobile station **30** are forwarded by the base station **13** to the BSC **11**, and thence to the fixed end system **17**.

FIG. **3** shows the configuration of the ATM connections during a BS—BS handoff from the old base station **13** to a new base station **14**. The BSC **11** has determined that the handoff is available or required. This determination may take one a number of forms. In the preferred embodiment the mobile station **30** reports signal strength and bit error rate measurements to the BSC **11** indicating the need for a handoff. Either the mobile station **30** reports to the BSC **11** the detection of synchronization cells (F3 cells) transmitted by base station **14** and identifying base station **14** or base station **14** reports to the BSC **11** the detection and reception of ATM cells from the mobile station **30**.

The BSC **11** uses existing ATM call control signaling protocols to add a leg **50** to the downstream connection, having as its destination the new base station **14**. It further uses the signaling protocols to establish an upstream connection **51** to the new base station **14**. In the downstream virtual connection, the ATM network node **21** bifurcates the ATM cell stream into connections **41** and **50**. This is achieved by the BSC **11** providing the node **21** with ATM signaling requesting the bifurcation.

Thus, in FIG. **3**, the mobile station **30** is receiving two copies of the cell stream that originated in the fixed end system **17**, and the BSC **11** is receiving two copies of the cell stream that originated in the mobile station **30**. Initially, the mobile station and the BSC each discard cells received from the new base station **14**, and continue to consume cells received from the old base station **13**. After synchronization (described below with reference to FIGS. **8** and **9**) is performed, the mobile end system and the BSC discard cells received from the old base station **13** and consume cells received from the new base station **14**.

FIG. **4** shows the configuration of the ATM connections after the BS—BS handoff. After it has completed synchronization, the BSC uses the existing ATM call control protocol to release the old upstream connection **42**. Similarly, after it has completed synchronization, the mobile station **30** drops the old leg of the downstream connection **42**.

FIG. **5** shows the configuration of the ATM connections for a BSC-to-BSC handoff as mobile station **30** moves from the coverage area of BS **14** to the coverage area of base station **15** served by BSC **12**.

Mobile station **30** reports through base station **14** that it is receiving cells from base station **15** and optionally reports the signal strength and/or bit error rate of those cells. The preferred operation is that mobile station **30** passes these cells to BSC **11** and BSC **11** examines the error rate within the cells by performing error detection on the cells.

As a third alternative, base station **15** reports to BSC **12** via node **23** the detection and reception of ATM cells from mobile station and BSC identifies that BSC **11** is the BSC serving the mobile station and reports to BSC **11** that there is an opportunity for a handoff. BSC **12** identifies BSC **11** as the serving BSC either by interrogation of surrounding BSCs or by information reported to it periodically from surrounding BSCs as to the identification numbers of mobile station being served by the surrounding BSCs.

Node **21** (or some other node) is instructed by BSC **11** to bifurcate the downstream connection **50** and establish a connection **60** to BSC **12**, where the connection is made through first port **24**. BSC **12** in turn establishes a connection **61** through its other port **25** to base station **15** via node **23**. BSC **12** then establishes an upstream connection **62** to BSC **11**. BSC **11** combines the upstream connection **62** with the upstream connection **51** in a manner described below.

Finally, as shown in FIG. **6**, BSC **11** instructs node **21** to drop downstream connection **50** and mobile station **30** drops the upstream connection **51**.

FIG. **7** is a ladder diagram showing the exchange of signaling messages for a BS—BS handoff as shown in FIGS. **2**, **3** and **4**. The messages indicated by thin lines are standard ATM connection control signaling messages. The message **70** indicated by the dotted line is an additional messages sent between the BSC **11** and the mobile station **30**. The vertical

lines show elements of the connection configuration. Messages **75** and **76** are setup and connect messages for the downlink connection between the base station **14** and the mobile station **30**. Messages **77** and **78** are setup and connect messages for the uplink connection between the base station **14** and the mobile station **30**

In the process of ATM signaling to add or remove legs from connections, there is a correlation identifier which is part of the signaling message sent (by the mobile station or the BSC) to the network and transferred end-to-end. This identifier maps the VPI and VCI combinations between the connection for the old base station with the VPI and VCI combination for the connection to the new base station. Each of the messages indicated by the thin lines in FIG. **7** carries this correlation identifier.

Reference is now made to the handoff process and the appropriate VPI and VCI selection in the downlink connection setup message **75** in FIG. **7** in which the base station **14** sends a setup message to the to the mobile station **30**. The VPI is generally unique for the connection between the two end points and is selected by the base station **14**. The VCI can be the same as for the cell stream from base station **13** to mobile station **30**.

Mobile station **30** receives from BSC **11** a correlator identifier identifying that the new connection (having a new VPI and VCI) is the same as the existing connection through the old base station. Mobile station **30** is able to distinguish between the cell streams by virtue of the different VPI/PCI combinations. BSC **11** instructs mobile station **30** to initiate a handover to the new virtual connection identified by the correlation identifier and the new VPI/VCI combination.

It is preferred that across the whole network **20** the whole domain of VPI numbers, at least for downlink connections, is subdivided into mutually exclusive sub-groups of VPIs (or VPIs and VCIs) and that any given base station uses only its allocated sub-group of VPIs. These are stored in the connection identifier memory **35** or **36** for the base station. Adjacent base stations are, as far as practicable, not allocated the same subgroup of VPIs. This has an advantage similar to the reuse of frequencies in an FDMA system in that the VPI sub-groups are re-used across the network and confusion is avoided at the overlapping regions of base stations or the overlapping regions of networks. In one of the final steps of the handoff process, the VPI number may be changed to a new VPI number selected by the new base station. In this embodiment the VPI number is temporarily out of the sub-group of VPI numbers allocated to the base station and is chosen from within that sub-group when it is updated.

In operation, an ATM communication connection is established between the mobile station **30** and the old base station **13** with at least a first virtual connection identifier (preferably a VPI) selected from the connection identifier memory **35**. When it is determined that handoff conditions are met for a handoff to the new base station **14**, base station **14** selects a second virtual connection identifier (including a second virtual path identifier and a second virtual circuit identifier) for a downlink connection between the new base station and the mobile station. In the preferred method, the new base station **14** at least temporarily selects the existing virtual path identifier and the existing virtual circuit identifier as the new virtual path identifier and the new virtual circuit identifier for uplink communication. At least one of the second virtual path identifier and the second virtual circuit identifier (preferably the former) is later changed to a new value. Thus the first base station **13** is provided with a first sub-group of virtual path identifiers in memory **35** for use in communications with the mobile station **30** and the second base station **14** is provided with a second sub-group of virtual path identifiers in memory **36** for use in communications with the mobile station **30**, which is mutually exclusive to the first sub-group of virtual path identifiers, and the second virtual path identifier is (later, if not initially) selected by the base station from the second sub-group.

Each base station communicates with its mobile stations through ATM cells and each base station transmits physical layer synchronization cells using its own synchronization timing. ITU Rec. 1.610 describes various types of cells including F3 cells and F5 cells. Synchronization takes place in the physical layer using F3 cells and in the ATM layer using F5 cells.

In the physical layer, the physical radio channel is divided into frames. One frame comprises a fixed number of cells, there being preferably more than 10 and less than 50 cells per frame. Each Nth cell is a synchronization cell (where $10<N<50$) which can be considered to be an F3 cell. Thus the frames received by the mobile station **30** from base station **13** may be offset from the frames received from base station **14**. The offset is not necessarily a whole number of cells, but is entirely arbitrary. This is advantageous from a cell planning point of view. Operation takes place at a basic frame rate, with all transmissions being at integer multiples or devisors of the frame rate. A virtual connection comprises one or a plurality of cells per frame, depending on the desired data rate and the available capacity.

Each cell has a header (described below with reference to FIG. **12**) identifying the VPI and the VCI. Cells with the same VPI and VCI are collected by the base station (in the uplink direction) or the mobile station (in the downlink direction) into blocks of cells. The first cell of each block is an ATM synchronization cell, which can be considered to be an F5 cell.

FIG. **8** is a time sequence diagram, showing the timing relationship for blocks of cells between the cell stream **100** from the old base station **13** and the cell stream **102** from the new base station **14** in scenarios where the fixed delay from the new base station is approximately the same as the fixed delay from the old base station. The figure also shows an alternative cell stream **104** from the new base station where the fixed delay from the new base station is greater than the fixed delay from the old base station and a further alternative cell stream **106** where the fixed delay from the new base station is less than the fixed delay from the old base station.

Synchronization cells **110**, **111** and **112** are present in the cell stream from the old base station **13** at intervals of fixed numbers of cells, where the interval is known to the base station, mobile end systems and BSC. Synchronization cells **120**, **121** and **122** are present in the cell stream from the new base station **13** at the same intervals. (In cell stream **106** a further synchronization cell **123** is shown.) In each case, the differential fixed delay is approximately equal to the difference in arrival times between a synchronization cell from the old BS and the corresponding cell from the new BS. Due to the effect of delay jitter and queuing delays, the exact difference is not known. In each case a splicing arrangement is needed to seamlessly end the cell stream **100** from the old base station and pick up the cell stream **102**, **104** or **106** from the new base station without omitting or repeating cells.

FIG. **9** is a time sequence diagram, showing the operation of the splicing process carried out in the mobile end system, where it acts upon the two legs **41** and **50** of the downstream virtual connections that arrive from the old base station and

the new base station **13** and **14**, respectively. The splicing process also occurs in the base station controller **11** (the 'anchor' BSC), where it acts upon the two upstream virtual connections **42** and **51** that arrive from the old base station and the new base station, respectively.

FIG. **9** shows the cell streams **100** station, the cell stream e station, the cell stream **102** received from the new base station, and the cell stream **200** emerging from the splicing process, respectively. For illustration, cells received from the new base station are in phantom outline. User data cells **130**, **131** etc. are designated sequentially (i.e., n, n+1, n+2, etc.), and synchronization cells **110** are designated sequentially (i.e., $sync_m$, $sync_{m+1}$, etc.), where any cell so designated is identical whether received from the old base station or the new base station. At the beginning of the splicing process, user data cells n, n+1, n+2, n+3 received from the old base station become the output of the splicing process. The splicing process awaits synchronization cells. If synchronization cell **110** ($sync_m$) is received first from the old BS, then the splicing process discards subsequent user data cells **134**, **135**, **136** etc. (labeled n+4, n+5, etc) from the old BS, awaits the corresponding synchronization cell **120** ($sync_m$) from the new base station, discards the synchronization cell **120**, and then the output of the synchronization process becomes user data cells **154**, **155**, **156**, **157** etc. (labeled n+4, n+5, etc.), received from the new BS.

Referring to FIG. **10**, if synchronization cell **120** ($sync_m$) is received first from cell stream **102** from the new BS **14**, then the splicing process stores, in a first-in-first-out (FIFO) fashion, user data cells **154**, **155** and **156** (n+4, n+5 and n+6), until the corresponding synchronization cell **110** ($sync_m$) is received from the old BS; at that time, the stored user data cells **154**, **155**, **156** are removed from the FIFO storage, and become the output of the splicing process; when the FIFO storage becomes empty, then subsequent user data cells **157** received from the new BS become the output of the splicing process.

Cells may need to be removed from the FIFO storage at a rate which is paced by the peak cell rate, sustainable cell rate or available cell rate.

Referring now to FIG. **11**, details of a BSC **11** (or **12**) are shown. The BSC comprises an ATM switch **300** having input port **301** arranged to receive virtual connections **42**, **51** and **62** (and the downlink part of connection **40**) from node **21** of the ATM network **20** (these virtual circuits being bundled by node **21** over the same virtual path). It has combiner **303** coupled to switch **300** and an output port **304** for coupling to node **21** (or to some other node in the sub-network on the fixed side). Combiner **303** comprises buffers **306** and **307**, splicing element **308** and processor **309**. The BSC **11** also has an input port **320** for coupling to node **21** (or to some other node in the fixed end system subnetwork) coupled to an output port **321** for coupling to node **21** or some other node in the sub-network on the mobile side. In addition it has ATM signaling circuit **330** having an output **331** coupled to output port **321** and it has control processing element **332** coupled to the combiner **303** and the ATM signaling circuit **330** for control of those elements.

In operation, the scenario will be considered where a BS-to-BS handover is in progress at the stage shown in FIG. **3**. Virtual connection **42** from base station **13** and virtual connection **51** from base station **14** are received on port **301** (together with the downlink part of connection **40** which need not be considered). ATM cells of connections **40** and **51** are presented at port **301** with the same virtual path numbers. ATM switch **300** separates these cell streams by their different VCIs and passes them to buffers **306** and **307**. One of buffers **306** and **307** acts as a FIFO to buffer up cells arriving from the new base station (over connection **51**) when the synchronization cell **120** arrives from connection **51** before the synchronization cell **110** from connection **40**. Processor **309** removes the synchronization cells **110** and **120** and performs the other operations of the splicing process described above, including the control of the rate of removal of the cells from the buffers **306** and **307**.

For the downlink direction, ATM signaling circuit **330** issues ATM commands **334** and inserts these into the downlink connection to the ATM network node **21**. These messages include messages to: (a) establish new connections; (b) add new legs to existing connections; (c) remove legs from existing connections and (d) drop connections. Thus ATM signaling circuit **330** issues an instruction to node **21** to add leg **50** to existing connection **41**.

Thus it has been described how existing point-to-multipoint and point-to-point unidirectional ATM connection configurations are used in a novel way, along with standardized connection control signaling procedures, to transport a bifurcated ATM cell stream during a handoff. Existing, standardized, operations and maintenance (OAM) cell formats and procedures are extended to synchronize the handoff such that duplication and misordering are prevented, and loss is avoided. For real-time service categories, the synchronization procedures provide compensation of differential delay between the old path of the virtual connection and the old path of the virtual connection, so that CDV objectives can be met.

The arrangement has the advantages that: cells are not duplicated or misordered during handoff; for non-real time services, cells are not discarded if buffers are dimensioned properly; for real time services, CDV objectives are met, or cells are discarded; further, if sufficiently conservative CDV objectives are set, cell discard does not occur; the path of a connection follows a spanning tree from the anchor base station to the mobile end system; thus, the number of connection segments (and the corresponding resources) is minimal; standardized ATM layer and ATM signaling protocols are built upon but not modified

In this manner, combining of virtual circuits on the uplink and bifurcating of virtual circuits on the downlink is achieved.

The above description has set out the elements of the network infrastructure and their operation. The features of the mobile station **30** and the novel air interface between the mobile station **30** and its base station are now described.

It has been described that in the radio interface physical layer the radio channel is divided into frames, each frame comprising a fixed number of cells and each Nth cell being a synchronization cell (where 10<N<50). FIG. **12** shows a bit map for the header of a cell, whether this is a data cell or a synchronization cell. ATM cell header part **400** comprises 5 octets. Four bits are for generic flow control, eight bits are for VPI, 16 bits are for VCI, 3 bits are for payload type identifier, one bit is for cell loss priority and one octet is for header error control. It can be seen that the VPI and the VCI are a fixed resource. There is a need to make efficient use of this resource. The PTI field identifies, among other things, whether the cell is a synchronization cell or some other cell type.

Added to the ATM cell header part **400** is a physical layer part **401**. Physical layer part **401** is shown as comprising only one octet, but may be longer. For present purposes, it

is illustrated as having sufficient space for a cell sequence number of 8 bits.

The header shown in FIG. **12** accompanies a payload of 48 octets. This is fixed in the ATM network but may have a trailer added in the physical layer, for example giving extra cyclical redundancy checking or other error control code.

As an alternative arrangement to that illustrated in FIG. **12**, physical layer header **401** is omitted and a cell sequence number is inserted in the ATM header **400** in place of some of the fields shown. For example, the GFC field can be omitted and the four bits of this field together with four bits of the VPI field (or four bits of the VCI field) can be used as a sequence number field. The sequence number field is preferably large enough to span several blocks of cells. If, for example, the block size is 64 cells, an 8-bit sequence number field spans **4** blocks before it has to repeat. By providing a block sequence number in each block, these two numbers together uniquely identify a cell over a very large number of cells.

Referring to FIG. **13**, elements of an example of a mobile station **30** in accordance with an aspect of the present invention are shown. The mobile station comprises a transmitter **501** and a receiver **502** coupled to an antenna switch **503** and, through the antenna switch, to an antenna **504**. A synthesizer **505** is coupled to each of the receiver **502** and the transmitter **501**. A demodulator **510** is coupled to receiver **502**. A modulator **511** is coupled to the synthesizer **505**. A logic unit **520** is coupled via data lines **521** and **522** to the demodulator **510** and modulator **511**, respectively, and is coupled by control lines **523** and **524** to the demodulator **510** and the receiver **502** and to the transmitter **501** and the antenna switch **503** respectively. A control bus **526** is coupled between the logic unit **520** and the synthesizer **505**. Synthesizer **505** and control bus **526** are optional, as it is not necessary for the mobile station to perform FDMA channel changing, nor is it necessary to perform CDMA spreading and de-spreading. Instead of an antenna switch **103**, a duplexer can be used, allowing simultaneous receiving and transmitting of ATM cells. Logic unit **520** has an associated FIFO buffer **540**.

Coupled to the logic unit **520** via a digital bus **528** is a processor **530**. Coupled to the processor **530** is a random access memory (RAM) **531**, a program memory in the form of electrically erasable programmable read-only memory (EPROM) **532**, an operator interface **533** such as a keyboard and display and an I/O interface **535**.

In operation, the logic unit **520** receives data for transmission from the processor **530** and generates ATM cells. The ATM cells are created by assigning an ATM header to each cell comprising a virtual path identifier and virtual circuit identifier for the particular transmission. Logic unit **520** adds a physical layer header (and trailer if required) providing a sequence number for each sequential cell and supplies the resultant transmission burst data to modulator **511**. It will, of course, be appreciated that alternative arrangements can be provided. For example the addition of the physical layer header and trailer, can be carried out in processor **530**.

The logic unit **520** passes the transmission burst data to the modulator **511** bit-by-bit and provides a transmitter key-up signal on control line **524** (at the same time switching antenna switch **503** to the lower position as shown). The logic unit **520** controls the timing of key-up of the transmitter **501**, so that each transmission burst is transmitted at a carefully selected time in a frame.

When the transmitter **501** is not keyed up for transmission, the control line **524** causes the antenna switch **503** to switch to the upper position as shown, allowing ATM cells (with physical layer header and trailer) to be received via the antenna **504** to the receiver **502** and demodulated by the demodulator **510** and passed to the logic unit **520**.

The received ATM cells are identified in the logic unit **520** by the virtual path and virtual circuit identifier in the header **400** and only cells received with the appropriate virtual path and virtual circuit identifier are selected by the logic unit **520** for further processing. Logic unit **520** orders the received ATM cells in the correct order as defined by the sequence numbers in the physical layer headers **401**. Logic unit **520** also performs error correcting in a manner known in the art. When the data has been corrected, the data is passed on to the processor and to the upper layers of the protocol.

The processor **530** can perform the operation of assembling and ordering the ATM cells and can perform the error correcting if desired, but these functions can generally be performed more quickly in the logic unit **520**.

Logic unit **520** provides wake-up signals over control line **523** to receiver **502** (and to other parts of the mobile station) causing receiver **502** to power up and power down. Powering up and down of a receiver in response to a signal is readily understood by one skilled in the art and details such as an electronic switch and a battery power source need not be described here.

Logic unit **520** also controls synthesizer **505** via control bus **526** to select appropriate frequencies for transmission and reception depending on the particular frequencies of the system and the modulation scheme and other aspects of the physical layer.

FIG. **14** is a timing diagram for the purposes of illustrating operation of the mobile station **30** of FIG. **13**. In the upper part of the diagram there is a cell stream **700** which is the activity in real time on the downlink of the first ATM radio channel **31**. The cell stream **700** comprises a number of transmission bursts **701**, **702** etc., each burst comprising one ATM cell with its radio interface header and trailer. For the purposes of illustration, the first burst **701** shown comprises a synchronization cell S1. This is a physical layer synchronization cell, distinct from synchronization cells **110** and **120** of FIGS. **9** and **10** which are ATM layer synchronization cells. This burst **701** and later synchronization cell burst **710** are separated by one frame of N ATM cell bursts **702**, **703** etc. (the diagram is not to scale, as there is a discontinuity shown between ATM cell burst **706** and synchronization cell burst **710**). In the example illustrated, bursts **706** and **715** contain cells having the same VPI and VCI (connection A) and bursts **703**, **704**, **712** and **713** contain cells having another VPI and VCI (connection B). One of these cells may be ATM layer synchronization cell **110**.

Below cell stream **700** is illustrated cell stream **720**. Cell stream. **720** is the activity in real time on the downlink of the second ATM radio channel **32** and comprises physical layer synchronization cell bursts **721** and **730** marking the frames on the physical channel. These are separated by the same frame length (N cells). Bursts **726** and **735** show another independent connection on the channel (connection C). Bursts **725** and **734** show that the ATM cells of connection A are being received on this physical channel. Note that the frequency and bandwidth of this channel are the same as the frequency and bandwidth of the physical channel supporting cell stream **700**. Note also that there is not necessarily any code-divided spreading of the different physical channels. The two channel are able to co-exist by virtue of careful selection by each base station-mobile station pair of time slots that are available for that pair.

Thus, for example, connection C in cell stream **720** is established during gaps in the cell stream **700**. Connection A over cell stream **700** is also established during gaps in cell stream **700**. Synchronization cell bursts **721**, **730** in cell stream **720** are shown as coinciding with cell bursts **703**, **704** etc. because it is wholly possible that bursts **721**, **730** etc. do not interfere with the mobile station communicating over bursts **703**, **704** etc. by virtue of the location of that mobile station and its power selection.

Time lines **740** and **750** show wake-up times for mobile station **30**. Before the handoff, logic unit **520** of mobile station **30** is powering up its receiver **502** over control line **523** during time periods T1, T2, T3 and T4—that is to say only at times coinciding with bursts in the frame relevant to the mobile station **30** (in particular ATM cell bursts for the connection supported and synchronization cell bursts for the physical channel).

When a handoff conditions are met, i.e. handoff is perceived as available or a command is received from the communicating base station requiring a handoff, the logic unit **520** of the mobile station **30** powers the receiver **502** up by providing a signal over control line **523** for a longer time period T5 sufficient to encompass the arrival of synchronization cell burst **721** of cell stream **720** and ATM cell burst **725** of the connection supported. Thereafter it can power down until the next following synchronization cell burst **730** of the new base station cell stream **720**. Other arrangements can be envisaged where the mobile station extends its receiver wake-up time during the handoff and reduces it when synchronization of the cell streams is complete. At a minimum, it must remain in receive mode until synchronization cell burst **721** from the new base station is received.

Thus a method of operation of the mobile station has been described comprising the steps of powering up the receiver **502** during first time periods Ti corresponding to physical layer synchronization cells **701** arriving from the old base station and second time periods T2 corresponding to ATM cells arriving from the old base station, determining that handoff conditions are met and powering up the receiver for a third time period T5 longer than the first and second time periods. The third time period extends at least until a physical layer synchronization cell **721** is received from the new base station and preferably at least until an ATM cell **725** is received from the new base station following the physical layer synchronization cell from the new base station. After a handoff from the first base station to the second base station, the receiver is powered up during fourth time periods (T6 or T7) shorter than the third time period (T5).

Time line **760** illustrates operation of the mobile station **30** in transmission, i.e. the uplink cell stream over the R.F. interface. In transmission, during the handoff, the mobile station simultaneously transmits its uplink cells over the virtual connection to base station **13** and the virtual connection to base station **14**. This is achieved in one of two ways.

The first and preferred way is illustrated in FIG. **14** and shows that a cell **761** containing uplink data (or an uplink F5 synchronization cell) is transmitted and after a full frame period, the next cell **762** of the sequence is transmitted. These are marked as connection A' and form the connection to the old base station. As soon as possible after cell **761**, the same cell is transmitted but with the VPI and VCI appropriate to the connection to the new base station. This is shown as cell **771**, and a frame later the next subsequent cell **772** is transmitted. Thus there is duplication of the transmission of the cell payload, with different headers. Note that the locations of cells **761** and **771** are selected according to the activity on the uplink channel (which preferably has a different frequency band to the frequency band of the downlink channel but could indeed share the same frequency band). Note also that the timing of transmission of the uplink cells is selected so as not to coincide with the corresponding cells on the two downlink channels represented by cell streams **700** and **720**. This is advantageous for antenna switching and receiver sensitivity reasons.

The second way of simultaneously transmitting uplink cells over the virtual connections to the two base stations is by selecting the VCI and VPI for the new uplink connection as being the same as the VPI and VCI for the existing uplink connection and transmitting each cell only once. In this scheme, commands **77** and **78** of FIG. **7** do not require the establishment of a new connection, but command **77** merely informs the mobile station of the acceptance of the cells by the base station and command **78** is an acknowledgment. As one of the final steps of this handoff process, the VPI number can be changed to a new VPI number selected by the new base station.

FIG. **15** is a flow diagram illustrating a splicing process performed by the logic unit **520** of the mobile station **30** of FIG. **13**. In step **800**, the step in the handoff process has been reached at which duplicate cells are arriving at the mobile station **30** relating to the same communication, but arriving from different base stations in a manner the same as has been described with reference to the cell streams arriving at the BSC as illustrated in FIG. **8**. Received physical layer synchronization cells are discarded. In step **801**, cells from the new base station are stored in FIFO buffer **540**. When handoff conditions are met (step **802**), the mobile station **30** waits for the next (or first) ATM synchronization cell (similar to cell **120** in FIG. **8** but this time received over the air within one of cell bursts **725**, **734** etc.) from the new base station (step **803**). If in step **804** the ATM synchronization cell first arrives from the old base station (as in FIG. **9**), step **805** discards subsequent user data cells from the old base station and outputs to the higher layers of the protocol the user data cells from the new base station after synchronization with the new base station. Otherwise (step **810**) user data cells from the new base station are stored in FIFO buffer **540** until the next ATM synchronization cell (similar to cell **110** in FIG. **8**) is received from the old base station, in a manner similar to that shown in FIG. **10**. Eventually (step **812**) the ATM synchronization cells are discarded and the resulting continuous spliced cell stream is passed to the upper layers of the protocol and eventually to an application layer where the data is output to the user through operator interface **533** as voice or message text or video or in whatever form the application dictates or it is passed on to some other device over interface **535**.

The splicing process can be modified to include synchronization so that it supports real-time service categories. Each node in the ATM virtual connection, the base station and the BSC(s) are required in the standard ATM architecture to determine the maximum CDV that it will insert in the connection (its CDV allocation). This requirement is extended to also require a CDV allocation for the synchronization process, to be included in the CDV allocation of the BSC or mobile station in which the synchronization process resides. Further, the standardized ATM connection control architecture allows the BSC to determine the largest cumulative CDV that could be inserted by those nodes upstream of itself.

FIG. **16** and the following description describes further details of the splicing process performed in the logic unit **520** (or the processor **530**) in the mobile station **30**. Similar processing is performed in the BSC **11** (or **12**).

For real time service categories, the logic unit **520** and the processor **530** between them control the rate R at which ATM cells are transferred across the interface **535**. The rate R is ordinarily determined at connection establishment time using information contained in the standard connection control signaling messages. If ATM cells arrive at the logic unit at a rate faster than R, then the cells are stored in FIFO **540** (or in RAM **531**) until they are able to be consumed at the interface **535**.

Referring to FIG. **16**, the approximate differential delay D between the communication from the old BS and the communication from the new BS is measured in step **900** by determining the time between the arrival of a sync cell syncm−1 from the old BS and the corresponding arrival of syncm−1 from the new BS. If (step **902**) the absolute value of D is less than a predetermined delay value, then the splicing process proceeds in step **904** as shown in FIG. **9** or FIG. **10**. No further delay compensation is needed.

If step **906** determines that synchronization cell synchm−1 from the old base station arrives before synchronization cell synchm−1 arrives from the new base station, then in step **908** the synchronization process calculates a compensating FIFO depth F for FIFO buffer **540**, such that F is a number of cells that need to be stored to allow the handover to take place without exceeding the CDV allocation for the synchronization process. Step **910** then calculates a rate reduction factor r<1, such that R*r allows F cells to accumulate in the FIFO in k blocks. The value of r is further determined such that reducing the service rate in step **912** at interface **535** to R*r will not cause the CDV allocation to be exceeded. Except when D is exceptionally large, r will be equal to 1. When the FIFO contains F cells (step **914**), then splicing can proceed as illustrated in FIG. **9** (step **916**). At the same time (step **918**), the service rate at interface **535** is increased to R and the splicing process is concluded (step **920**).

If, in step **906**, synchronization cell synchm−1 from the old base station arrives after synchronization cell synchm−1 arrives from the new base station, then synchronization is performed as illustrated in FIG. **10** (step **930**). The clustered cells received from the new base station, cells **154**, **155**, **156**, are stored in the FIFO **540**. A rate increase factor r' is calculated in step **932** such that increasing the service rate at the interface **535** to r'*R will not cause the CDV allocation for the synchronization process to be exceeded. The service rate at the interface **535** is then increased in step **934** to r'*R. When the FIFO becomes empty (or nearly empty) as determined by step **936**, the service rate at interface **535** is reduced again in step **938** to R and the splicing process is concluded (step **940**).

Thus a handoff process has been described which comprises combining first and second cell streams in a remote station (mobile station) of a radio communications system, comprising: receiving a first cell stream **700** from a first base station **13**, the first cell stream including first synchronization cells (preferably ATM synchronization cells e.g. cell **110**, but alternatively physical layer synchronization cells e.g. cell **701**); receiving a second cell stream **720** from a second base station **14**, the second cell stream including second synchronization cells (preferably ATM synchronization cells e.g. cell **120**, but alternatively physical layer synchronization cells e.g. cell **721**); outputting the first cell stream until a first synchronization cell is received; receiving a second synchronization cell; and outputting the second cell stream following the second synchronization cell.

The handoff process has significant advantages over soft handoff processes in prior art systems such as CDMA systems, especially where data is conveyed, because it does not rely on correlation of the data content (e.g. voice correlation) but allows seamless splicing of the ATM cells carrying the data and avoids or minimizes data loss or duplication. It also has advantages in systems carrying data where service rate is important, such as video data, as it allows for smooth continuous flow control of the data without jitter.

Modifications of the arrangements described can be made within the scope of the invention. For example it has been described how sequence numbers are provided for individual cells and how sequence numbers are provided in ATM synchronization cells (F5 cells). As an alternative one or other of these sequence numbers can be omitted. Also it has been described how synchronization cell bursts (F3 cells) are provided in the physical layer and ATM synchronization cells (F5 cells) are provided in the ATM layer. In an alternative embodiment only one of these sets of synchronization cells are used.

What is claimed is:

1. A method of operation of a remote station of a radio communications system comprising a remote station and at least first and second base station, the remote station comprising the steps of:

powering up a receiver during first time periods corresponding to physical layer synchronization cells arriving from the first base station and second time periods corresponding to ATM cells arriving from the second base station;

determining that handoff conditions are met;

powering up the receiver for a third time period longer than the first and second time periods.

2. The method of claim **1**, wherein the step of powering up the receiver for the third time period comprises powering up the receiver at least until a physical layer synchronization cell is received from the second base station.

3. The method of claim **2**, wherein the step of powering up the receiver for the third time period comprises powering up the receiver at least until an ATM cell is received from the second base station following the physical layer synchronization cell from the second base station.

4. The method of claim **1** comprising the steps of performing a handoff from the first base station to the second base station and powering up the receiver during fourth time periods shorter than the third time period.

* * * * *